Discrete Event Simulation Helps to Improve Terminal Productivity for New Design Container Ships

Rasih Onur Süzen

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Supervisors : Prof. Ludmila Filina-Dawidowicz, West Pomeranian University of Technology, Szczecin, Poland
Prof. Jean-David Caprace, Federal University of Rio de Janeiro, Brazil

Reviewer: Prof. Philippe Rigo, University of Liege, Belgium

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ABSTRACT

Efficiency improvement in container terminal operations can lead to increase service capacity, reduce berthing time and operational expenses of ports. Moreover, being faster in ports allows a ship to transit at lower speeds (slow steaming) thus to save fuel as well as to reduce emissions, or else ship can sail at same speed to have higher annual cargo capacity and income.

Despite that there being researches about existing container terminal productivity assessment, no papers analyzing port efficiency of a new bay plan design of a container ship stochastically have been published.

This thesis proposes a productivity analysis of a new bay plan design which intends to be faster during loading and unloading at container terminals. The operational efficiency of a container terminal is investigated for various conditions and its effect on berthing time is reviewed.

Port productivity, i.e. the time needed to move a selected number of containers, is assessed using a Discrete Event Simulation methodology. A fully parametrical port simulation model is created and calibrated based on a 7 months statistical data set of a real container terminal. The uncertainties and unpredictable events i.e. several types of delays related to operations are implemented using semi-random numbers. Following the description of the stochastic parameters included in the model, the simulation is repeated until sufficiently large sets of iterations are available for statistical analysis. Then, the dispersion of results regarding the port productivity are discussed and compared to measured data.

Finally, we obtain the results concerning efficiency of a new bay plan where various conditions, such as the high/low tide, higher/lower crane speeds and multiple crane usage, are considered

We suggest that DES is one of the most precise analysis and decision assistance tool to accomplish operational performance studies for new bay plans and container terminals.

Keywords: Container terminal operations, crane efficiency, discrete event simulation, stochastic approach

Abstract (en Français)

La Simulation par Evénements Discrets Contribue à l'amélioration de la Productivité d'un Terminal portuaire pour le design de nouveaux Porte-Conteneurs

Par **Rasih Onur Süzen**

L'amélioration de l'efficacité dans les opérations de terminaux à conteneurs peut conduire à augmenter la capacité de service, réduire le temps d'accostage et les charges opérationnelles de ports. En outre, être plus rapide dans les ports permet à un navire de transiter à des vitesses inférieures (vitesses réduites) et d'économiser du carburant ainsi que de réduire les émissions.
Même s'il y a des recherches sur l'évaluation de la productivité du réservoir terminal existant, il n'y a pas de documents analysant l'efficacité des ports d'une nouvelle conception du plan de la baie d'un navire porte-conteneurs stochastique.
Cette thèse propose une analyse de la productivité d'une nouvelle conception du plan de cale qui a l'intention d'être plus rapide pendant le chargement et le déchargement aux terminaux à conteneurs. L'efficacité opérationnelle d'un terminal à conteneurs est étudiée pour différentes conditions et son effet sur le temps d'accostage est examiné.
La productivité du port, c'est-à-dire le temps nécessaire pour déplacer un certain nombre de conteneurs, est évaluée en utilisant une méthodologie de simulation par événements discrets (SED). Un modèle de simulation de port paramétrique est crée et calibré sur la base de sept mois de données statistiques d'un terminal à conteneurs réel. Les incertitudes et événements imprévisibles, à savoir plusieurs types de retards liés aux opérations sont mis en œuvre en utilisant des nombres semi-aléatoires. Après une description des paramètres stochastiques inclus dans le modèle, la simulation est répétée jusqu'à ce qu' un ensemble d'itérations assez grandes soit disponible pour l'analyse statistique. Ensuite, la dispersion des résultats concernant la productivité des ports est discutée et comparée aux données mesurées.
Enfin, nous obtenons les résultats concernant l'efficacité d'un nouveau plan de baie où diverses conditions sont considérées, telles que la marée haute / basse, la vitesse de la grue supérieure / inférieure et l'utilisation de la grue multiple.
Nous suggérons que le DES soit une analyse et un outil d'aide à la décision le plus précis possible afin d'accomplir des études de performance opérationnelle pour les nouveaux plans de cale et les terminaux à containers

Mots-clés: l'exploitation des terminaux à conteneurs, l'efficacité de la grue, la simulation par événements discrets, l'approche stochastique

Table of Contents

List of Figures

List of Tables

Abbreviations

ABRATEC	Brazilian Association of Public Use of Container Terminals
BCL	Batch Control Language
DES	Discrete Event Simulation
FEU	Forty-foot Equivalent Unit
GUI	Graphical User Interface
OOG	Out Of Gauge Cargo
QC	Quay side Crane
RTG	Rubber-Tyred Gantry Crane
SCL	Simulation Control Language
TEU	Twenty-foot Equivalent Unit

Declaration of Authorship

I declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

Where I have consulted the published work of others, this is always clearly attributed.

Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

I have acknowledged all main sources of help.

Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma.

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1. INTRODUCTION

1.1. Context

Container transportation has been increasing dramatically over the past decades across the globe leading us to several concerns regarding to efficiency of container ships and ports operations. It is stated that the annual global container throughput is presumed to reach 840 million TEU's by 2018, which would indicate a 100% increase compared to 2004 [1]. As a consequent of this massive growth, congestions at container terminals are caused, such as in September 2014, when it was reported that Asian ports are facing the worst congestion of the last two decades [2].

Additionally, after the downturn of the global economy in 2008, energy efficiency has become one of the main concerns for maritime operations. Especially in the container shipping sector decreasing freight rates, increasing bunker, lube oil, manning, maintenance costs induced ship owners to find ways to reduce operational costs. As the single biggest cost factor in merchant shipping, solutions regarding fuel consumptions were considered [3].

The simplest way to reduce this cost is to reduce ship speed, which is can be defined as slow steaming. Figure 1 states fuel consumption of ships of different size changing by speed.

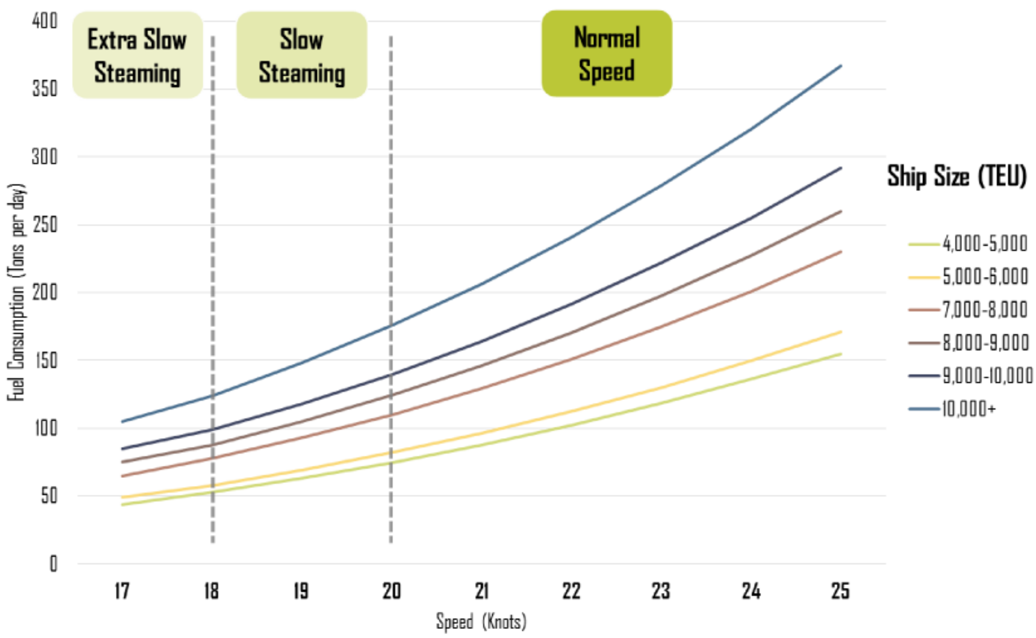


Figure 1. Ship Speed & Fuel consumption chart for ships of different size [4].

Considering these two problems stated above, a solution can be offered by improving container terminal efficiencies. It can increase the service capacity of terminals, reduce operational time of the ships at port, minimize the problems faced due to congestions hence reducing operational expenses. Furthermore, for ship owners, improved container terminal efficiency can let the ships sail for smaller speeds by applying slow steaming phenomenon, which leads ship to save petroleum as well as to decrease emissions.

It is a well-known fact that the hydrodynamic, propulsion and structural optimization are the fundamentals of a new ship concept. To perform an optimum design however, overall efficiency should be considered, where operational efficiency is one of the most important components. Like other concerns, operational efficiency should also be respected from the design stage of a container ship. When a life cycle time of a container ship is taken into account, a new bay plan configuration which is faster to load and unload in terminals can provide a significant productivity enhancement.

1.2. Background

This master thesis has been prepared within the framework of EMSHIP Advanced Masters in Naval Architecture program. The research has been accomplished as a research internship at Federal University of Rio de Janeiro (UFRJ) in the Simulation Laboratory of Ship Building Processes (LABSEN) under the supervision of Professor Jean-David Caprace, together with the support of the National Counsil of Technological and Scientific Development (CNPq) of Brazil. The thesis has been written during the last semester of EMSHIP program, under the administration of West Pomeranian University of Technology (ZUT), Szczecin, Poland, and under the supervision of Professor Ludmila Filina- Dawidowicz from ZUT.

1.3. Gap

Simulation of container terminal operations is a topic that has been studied since 1970's. In scientific literature, there are various papers having different approaches, proposals and objectives, some of which are processed using Discrete-Event Simulation (DES) methodology. Furthermore, there also exist statistical approaches applied on examining the terminal efficiency of new bay plan designs for container ships, which will be widely discussed in chapter 2.1.

However, there is not any paper or published research to focus on the terminal productivity concerns of a new bay plan design for a container ship by using DES model. Earlier, a research was carried out by Harries et. al. [5], where the efficiency calculations were performed with a statistical approach. This master thesis is a further research of the aforementioned paper, where the efficiency of the new bay plan design is analyzed stochastically using a DES model, in order to produce more precise results and examine the effects of various conditions on operational time of the new container ship. One of the main differences from the earlier study is that several uncertainties are considered that directly influence berthing time of the ship. In different sections of the paper, improvements will be explained with details. (See chapters 3.3, 3.4 and 4.3)

1.4. Objectives

This thesis mainly focuses on port efficiency analysis of a new bay plan design for a container ship which aim to be faster during loading and unloading of containers at terminals by using Discrete Event Simulation (DES) and shows the effect of different cases on total operational time.

The study is structured as a further research carried out by Dr. Harries from FRIENDSHIP SYSTEMS GmbH, and published in a paper named “Port Efficiency Simulations for the Design of Container Ships” [5], where port efficiency of a bay plan was examined with a statistical approach by taking into account many different loading scenarios and various number of containers.

In this thesis, one specific bay plan is investigated with one realistic container stowage case and previous research is improved in terms of realistic features: Employing operational data obtained by Libra Container Terminal (Rio de Janeiro, Brazil) and validating the simulation with 7 months of operational data as well as one real operation case performed in the terminal. The main interest in reducing the time spend in port for a ship is to sail at slower speed to the next destination and save combustible by using slow steaming policy. This advantage can also be utilized to increase number of containers carried annually, by travelling in the same speed.

The secondary aim of this research is to generate an interest of using DES for port operations and management decisions. The created simulation model may not only be used for new bay plan efficiency investigations, but can also be adopted as a tool to examine the efficiency of existing terminals, to identify the effect of different operational strategies, i.e. stowage sequence effects, defining number of cranes per operation.

1.5. Structure of the Thesis

The introductory chapter of this thesis mainly contains the information concerning the background of container terminal operations and current problems, the scientific gap regarding why it is needed to perform such a study and objectives with respect to the aims of the overall work.

In chapter 2, the current literature related to port operational efficiency and port simulations is discussed briefly. Discrete Event Simulation is explained and the reasons for choosing this methodology are justified.

Brief information regarding the analysed container terminal is provided in chapter 3. The key data analyses made concerning port operations are explained. Focus is placed on the "Analysis of Operation Delays" that are used in the simulation model.

In chapter 4 the structure of the research and the simulation model architecture are presented. Brief information is given about the elements and the creation processes of the simulation model, including the description of the simulation system, data implementations, improvements and added features. Crane productivity calculation method is explained, furthermore, calibration of simulation model is performed. Lastly, three main simulation cases are briefly described.

Chapter 5 contains the results of the three main simulation cases. Simulation results are compared with the results of statistical approach.

Chapter 6 is dedicated to demonstrate the conclusions derived from the obtained results. Additionally, suggestions for further researchers take place in this chapter.

Chapter 7 is devoted to acknowledgements and giving thanks to people who made a contribution to this thesis.

Lastly, in Chapter 8 analysed literature, journal articles, books, thesis and internet-based sources are stated as references.

2. STATE OF THE ART AND METHODOLOGY

2.1. State of the Art

Container terminal simulations have been performed for almost 45 years now. It is beyond doubt that the power of this tool has been rising with the improvements in computer technology. Since 1970s, there has been some major researches in this field and the following section some of them will be devoted and discussing some of the seminal work.

As a starting point, one of the oldest paper in the literature produced by Nehrling [6] was chosen. It concerns container ship handling operations and the simulation, which was performed on IBM's General Purpose Simulation System (GPSS), wherein the mathematical modelling of a general container handling system is taken into account.

The research of Liu [7] focuses on how to improve the scale efficiency of any particular port or terminal. It explores efficiency analyses of North Mediterranean container ports and terminals. However, the study does not particularly emphasise on the quayside crane simulations. Therefore, this thesis is more useful as a source of information about the efficiency of internal activities of a port.

In the paper of Goussiantiner [8] the advantages of multi-trailer systems for a container terminal are stated. It also provides a SWOT analyses (Strengths, Weaknesses, Opportunities and Threats) and discussions about the potential improvements on terminal efficiency by use of multi-trailers. This paper will be considered for future improvements on the simulation model.

The following study named "Optimizing Maritime Container Terminal Operations" authored by Gadeyne&Verhamme [9] focuses on the double cycling in the quay crane scheduling problem by considering important operational parameters and limitations. Several methods are used to optimize the sequence of containers in a bay. As a result, the research presents up to 10% turn-around time depending on the given stowage plan. Yet, operational times are calculated by using constant cycle times.

Furthermore, Won&Kim [10] aim to construct an efficient operational plan in container terminals and put forward a unified framework. The paper underlines that a large number of factors must be considered for the decision-making process on a container port operation. Although the paper proposes ideas about quay crane scheduling, the methodology used only provides crane operational time calculations mathematically.

Another approach is suggested by Fan et. al. [11] , where an effective algorithm is described for generating basic stowage plans of large containership calling at a given number of ports. It is focused on automation of container handling systems. Crane intensity and re-handles are also studied. In the paper, ship stability concern is taken into account as well. Furthermore, a case study is involved about the analysis of the stowage plan on critical measurements. The heuristics proposed in the paper can be applied for new block-based stowage plans.

Moreover, Rizzoli et. al. [12] model a container terminal simulation by using a stochastic approach to evaluate the effect of new operation policieswith the aim of drawing attention to usage of simulations on container terminals in decision-making and management activities. However, the study mainly concentrates on the performance of the terminal in general, not any specific ship or loading condition.

Furthermore, Carteni [13] suggests Discrete-Event Simulation to estimate the whole performance of a container terminal. Different elements of a container terminal are surveyed stochastically, wherein the simulation model is created and calibrated according to the terminal in focus. As Rizzoli et. al. [12], this study is not focused on quay side activities and performance of any specific ship.

Ambrosino & Tanfani [14] are other authors who have an interest in operational decision-making problems of a maritime container terminal. In contrast to aforementioned papers, their primary concern lies in the seaside area of operations. They propose a Discrete-Event Simulation for crane assignment problem. However, similarly to the papers presented before, they are not involved in performance of new bay plan design of a container ship.

After reviewing papers and theses concerning port operations and simulations, slow steaming policy published by Maersk Lines is investigated [15]. A study carried out by Maersk Lines, the biggest container shipping company in the world, is taken into account from the economic and environmental point of view of slow steaming policy.

As this thesis aims to be a further research of Harries et. al. [5], this work has been chosen to conclude with. The study seeks to compare the port efficiency of different container ships. A Panamax ship (4250 TEU) and two other ships with the capacity of 3700 TEU are designed all of which have distinct bay plan configurations that target to have less operational time in port. The methodology chosen for the research is a statistical approach, wherein different numbers of containers distributed over the vessels and operational times are calculated for different number of cranes for each case. Crane speeds are considered as constant except in hatches where different crane speeds have been used. No accelerations were applied and similarly, hatch cover handling process is fixed as a constant time, (900 seconds per bay). In addition, uncertainties, i.e. delays, defects, other factors affecting operational time, were not considered. Taking this paper as an initial reference and using the 4250 TEU ship with one specific loading condition, DES approach is applied with a stochastic methodology. Uncertainties are implemented by delay distributions to produce results that are closer to reality. In addition, crane acceleration and speeds are implemented. Hatch covers are handled like container handling, which is the case for current operation. Moreover, FEU incorporation into the stowage plan is included in this study. All the improvements performed to the original model proposed by Harries et. al. [5] are put forward in capter 4.2 and 4.3.

2.2. Methodology

Container terminal operations can be described as non-continuous actions, where all the processes happen in a chronological order of events. For a quay crane, these activities can be considered as engaging the container, rising up, translating through the port, lowering down, disengaging, etc. Referring to Robinson [16], each event occurs at a particular instance in time and marks a change of the state in the system. In addition, Fishman [17] describes a Discrete-Event System as a procedure, where one or more phenomena of interest change value or state at discrete points in time, rather than continuously with time. These determinations direct us to adopt Discrete-Event Simulation (DES) as the methodology for this research problem. DES is a stochastic analysis of the combined probabilities of all events in the process flow, which leads to realistic predictions of the events' overall time. As Fishman [17] states, it is a model based on theory, i.e. new bay plan design, new stowage plan and detailed account based on empirical observations, which are the statistical analyses of delays, defects and container type distributions.

Even though container terminal operations can be highly automated, operational times still cannot be planned very accurately, due to many complexities such as the human factor, different equipment's delays and defects, weather conditions, etc. This combination of complexities causes difficulties for planning the berth occupancy and operational time precisely. By using DES, these complexities and the fundamental characteristics of a container terminal can be incorporated into the simulation and, finally, the performance of a new bay plan design can be analysed. This allows to see the general behaviour of the container terminal for different operational cases.

The main advantage of DES is the consideration of random factors that impact operation of the system. It provides a stochastic modelling, where the uncertainties on each of the processes are considered by use of different semi random numbers trough the seeds. For a container terminal, human, equipment and climate-related randomness can be introduced by using statistical data thus making it possible to create a system model for the obtainment of accurate and precise results.

DES has several major advantages compared to other simulation methods. First, it considers the simulated system in dynamics, considering its evolution trough time. In addition, DES allows users to understand the attributes of the observed system better. It gives clear results about the bottlenecks of the operation to improve quality. Moreover, it allows the user to apply different approaches or strategies regarding operation to see possible variations, thus providing the opportunity to perform a new strategy change to see its outcomes. A user can easily identify the most feasible way to allocate resources, machines, work force, e.g. for cranes in our study. Besides that, DES makes it possible to monitor the effect of altered inputs, i.e. higher/lower crane speeds, high/low tide for this simulation case. Indeed, it is less expensive than altering an existing system to study impact of changes.

Another important merit of DES compared to statistical modelling is that it provides the opportunity to work on systems, where new equipment is applied and a new operation strategy is followed. In such cases, there is no relevant data to perform a statistical analysis; however, it is possible to observe the results of interactions of new changes in the state of the system [18]. Productivity calculations of a new bay plan design of a container ship is a new application in the created system, therefore DES is a “tailor-made” methodology for this research problem.

Assumptions and Simplifications

- Crane speed in hold does not differ from crane speed over deck. In Harries et. al. (2013) simulation, crane speed in hold is taken as 0.7m/s and 1m/s over deck.
- Crane loaded speed and empty speed are taken to be equal.
- Delay distributions are created and a distribution-fitting test is performed. However, distributions do not satisfy the test due to lack of data. Therefore, the closest suggestion of distributions is chosen.
- Vessel is steady during the operation. Loading and unloading containers does not make any difference on the draft of ship. There is no disturbance due to waves etc.
- Weather conditions were not taken into account, i.e. wind, storm.
- Load case studied is feasible regarding to stability, strength, regulations and economic factors.
- Dangerous, reefer, special size/type of containers are not taken into account.
- Container weight or size does not affect the speed of crane.
- Sequence of container handling is not studied. Containers are handled starting from the highest to the lowest tier.

- Bridge of ship is taken as one FEU bay length.
- Each crane is equal, has equal speeds, accelerations and delay distributions.
- Reallocation of containers from one bay to another bay is not studied.

3. DATA ANALYZE AND IMPLEMENTATION

3.1. Chosen Terminal Characteristics

Understanding the dynamics of a container terminal has importance to perform a port operation simulation. To do so, some general characteristics of the surveyed terminal are given in this section. The container terminal inspected is located in Rio de Janeiro, Brazil and Libra Logistics Group operates it. It is established over 136 thousand square meters with 9 600 square meters covered warehouse space. In Figure 2, the storage area of the terminal, berths and some port equipment can be seen. It has two mooring berths that allows container ships up to 13 meters of draft to be moored. The mooring dock is 545 meters long with static capacity of 11 200 TEU/month. As one of the key elements of a port, four quay cranes are located on the quay side. Two of those cranes are eligible to operate for Post-Panamax ship, which can be seen on Figure 3 on the upper-left side.

Figure 2. Storage area and port side view of Container Terminal of Rio de Janeiro, Brazil [19] .

Figure 3. Four quay side cranes of the port before the operation starts. The crane identifications stated in the thesis from left to right: Crane 2, Crane 3, Crane 1 and Crane 2 [20] .

Figure 4 shows the annual number of containers handled in the terminal from the year 1998 to 2012. It can be easily deduced that except some years like 2005 and 2009, the terminal has a remarkable increase of total container numbers parallel to the growth of World container trade.

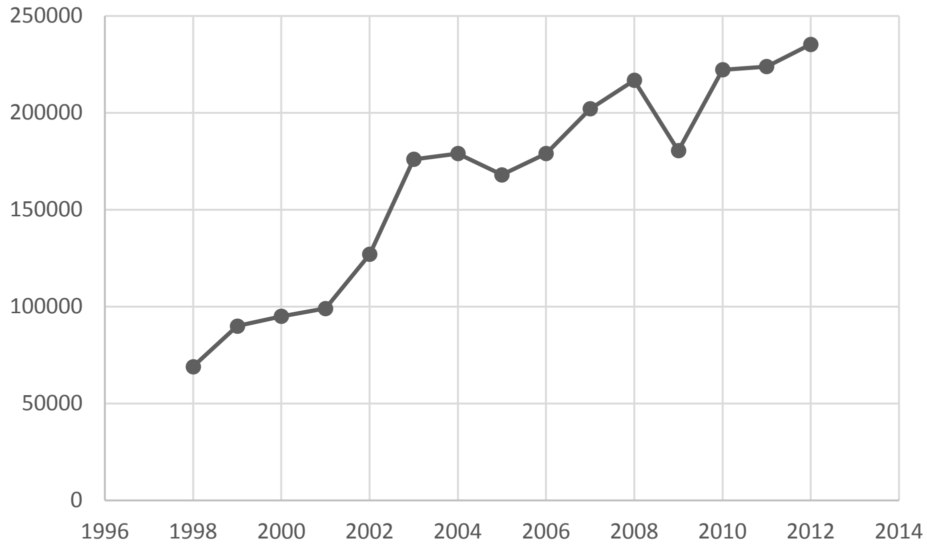


Figure 4. Annual operation growth of Libra Container Terminal, from 1998 to 2012, in TEUs [21] .

It can be noticed that Libra Terminal reached to total number over 235 thousand TEU in both export and import operations in 2012. Considering this dramatic growth over years, terminal decided to enlarge the operational and storage areas, as well as to kick in new equipment. Therefore, the construction of new mooring dock is on progress and two new Post-Panamax quay cranes and six rubber-tyred gantry cranes (RTG) are purchased, to respond this significantly boost of demand. These equipment will be started to use when the new mooring dock is ready for operations.

During the work process at Federal University of Rio de Janeiro, three visits were realized to Libra Container Terminal to exchange information and data regarding to process of work. These meetings are carried with Operation Manager Mr. Daniel Oliveira. Some technical and practical facts concerning to container handling and port operations are acquired and presented in different chapters of this thesis. According to him, Container terminal of Rio de Janeiro is the first and last terminal in South America for the ships transit in between South America to Far East[1]. It means that most of the handling operations inclined to be only for loading or only for unloading.

3.2. Analysed Data of Terminal

During this research, the data received from Libra Container Terminal is studied from several perspectives. The data contains 500 crane operations to serve 197 ship-berthing cases, where 78180 containers handled from 1 January 2014 to 6 August 2014.

The data includes following information:

- Main dimensions of the ships operated,
- Total number of different types of containers handled (TEU&FEU),
- Operation type (loaded, unloaded, re-handled etc.),
- Total berthing times,
- Total operational times,
- Number of cranes used per operation,
- The identification of cranes used in the operations,
- Number of hatch covers moved during the operations,
- Crane productivities,
- Various delay and defect time durations.

The analysis of the received data have been carried out and some of the important outcomes are presented in the following figures.

[1] Stated by Mr. Daniel Oliveria who is the Operation Manager at Libra Terminals at the first meeting on 23 July 2014.

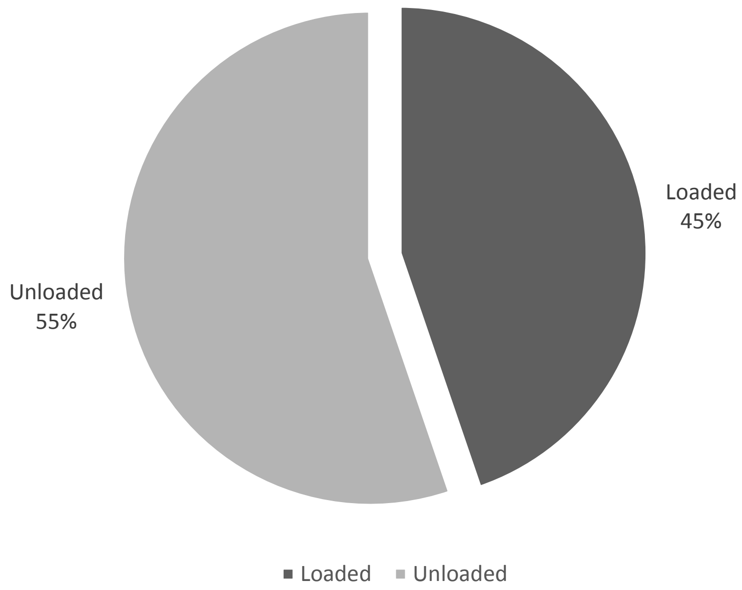


Figure 5. The Ratio of Loaded/Unloaded Container Numbers for the Terminal from 1 January 2014 to 6 August 2014.

Figure 5 provides information regarding to the operation type applied on 78180 containers. 55% of all the operations performed in the terminal is determined as unloading operation. It is an advantage to investigate a terminal where the most of the operations are observed as unloading, because stowage case chosen for the simulation cases concerns about mainly unloading operation.

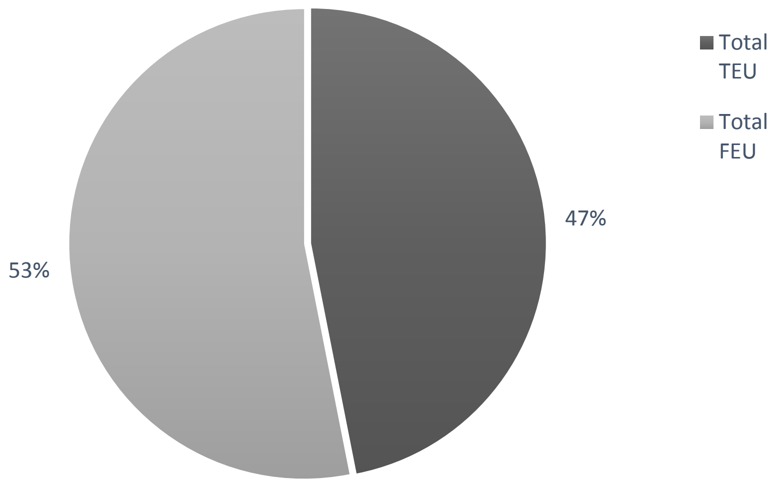


Figure 6. TEU/FEU distribution of all the containers handled in the terminal.

It is stated that 55% of all containers in World container trade are FEU, while 45% of containers is TEU [5]. Similar to that, the rates are observed as 53% FEU and 47% TEU in the studied container terminal, as it is presented on Figure 6. This rate is used during the conversion process of containers for a different simulation case, which will be discussed on Chapter 4.3.2 under the title of FEU Implementation.

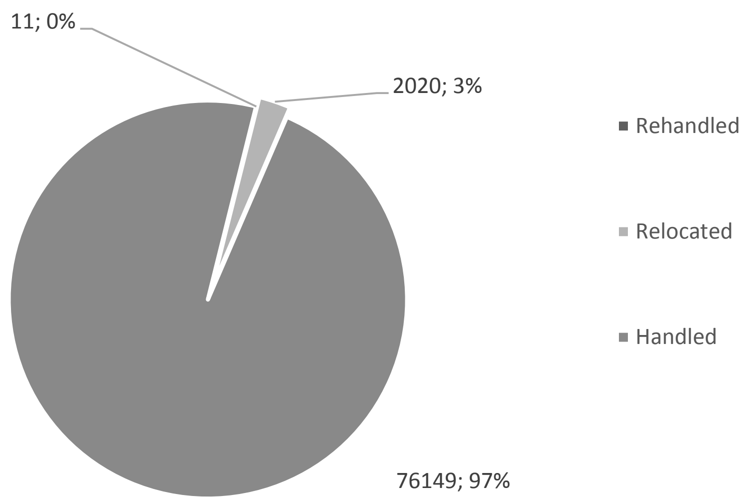


Figure 7. Container Handle/Re-handle/Relocation Rate and total numbers.

On the other hand, container handle, re-handle and relocation rates are given on Figure 7. In order to reach containers under hatches, hatch covers should be removed. In some stowage conditions, some of the containers are located on the hatch covers, which are not supposed to be unloaded at the current terminal. To be able to move the hatch covers, these containers are either relocated, or re-handled.

Container re-handle can be described as a process of unloading containers from the ship to shore and then loading back to the ship after operation under hatches is done. However, handling of such containers costs as two handling fee for the ship owner[2]. This is why, ship stowage planners pay severe attention to this issue. In Figure 7, it can be seen that only 11 containers are re-handled during 7 months of operations with 197 ships. On the other side, because of the same reason, some of the containers are decided to relocate on board. Mostly, they are taken to another row in the same bay of the ship, to prevent unnecessary movement of crane transversally. 3% of all the handled containers during 500 crane operations are detected as relocation operation. This operation is not considered for simulation cases.

[2] Stated by Mr. Daniel Oliveria at the terminal meeting on 03.10.2014.

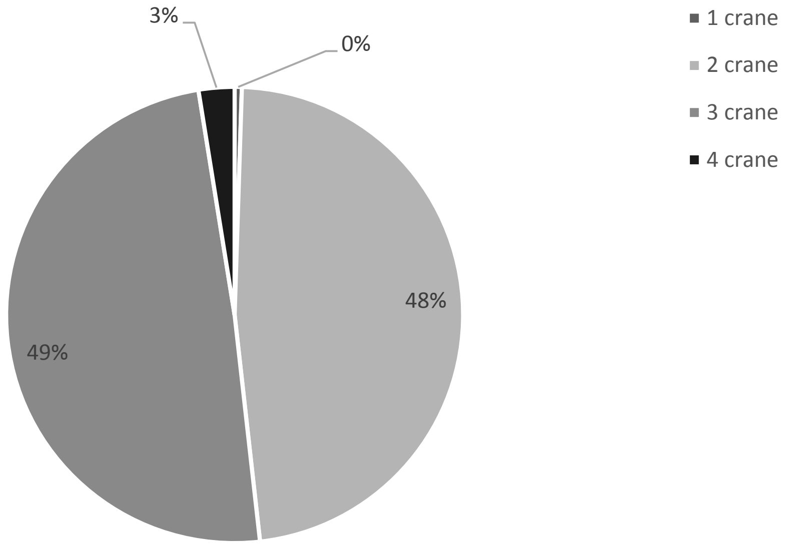


Figure 8. Number of Crane Usage Rate per operation.

Figure 8 states the crane usage preferences per operation in the terminal. Indeed, the number of used cranes depends on the total number of the containers to be handled, the largeness of ship, the schedule of next operation etc. Mainly two or three crane is decided to use for the operations. All four cranes of the terminal are used for 5 of 197 operations and only one operation is conducted using single crane.

On the other hand, Figure 9 presents the productivity of terminal cranes. Calculation method of crane productivity will be discussed on Chapter 4.4. It is observed that Crane 1 has sigfinicantly less productivity than the others. It is stated that the Crane 1 is the oldest crane of the port, which has lowest productivity, thus it is used very rarely during operations[3]. Taken this fact into consideration, Crane 1 is decided to be declared as ”outlier” (See Figure 3).

[3] Operation Manager of Libra Container Terminal Mr. Daniel Oliveria stated at the terminal meeting on 03.10.2014.

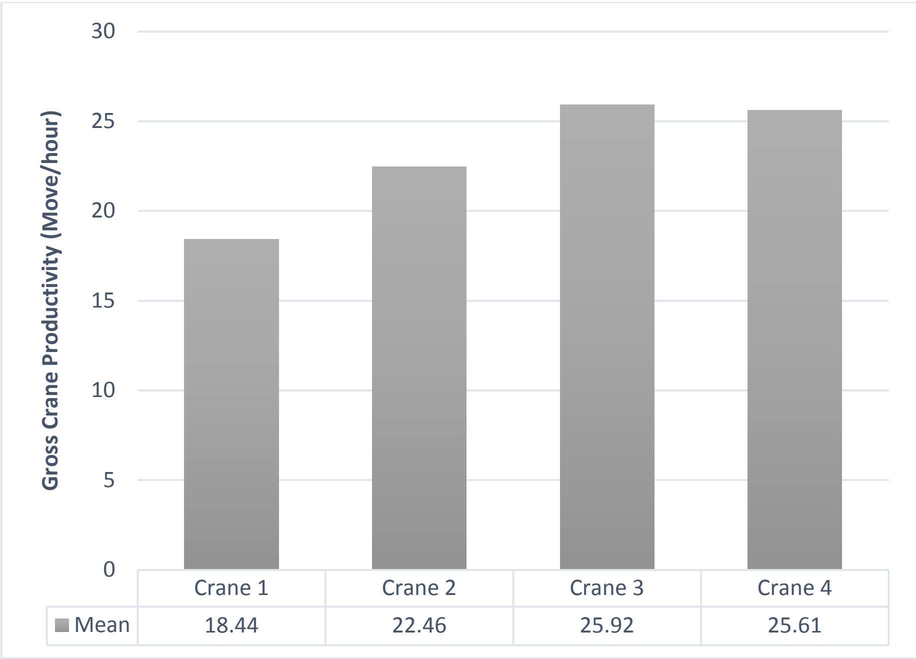


Figure 9. Average crane productivity assesment of container terminal in movement per hour.

After defining Crane 1 as outlier, the crane productivity histogram of Crane 2, Crane 3 and Crane 4 are created. An outlier test is performed for the operations of other three cranes and some of the operations are detected as outliers, according to 3-sigma rule. All the statistical analysis are performed with Minitab software.

As it can be observed from Figure 10, the average crane productivity is calculated as 25.18 move per hour, with a standard deviation of 4.207, with a sample number of 446.

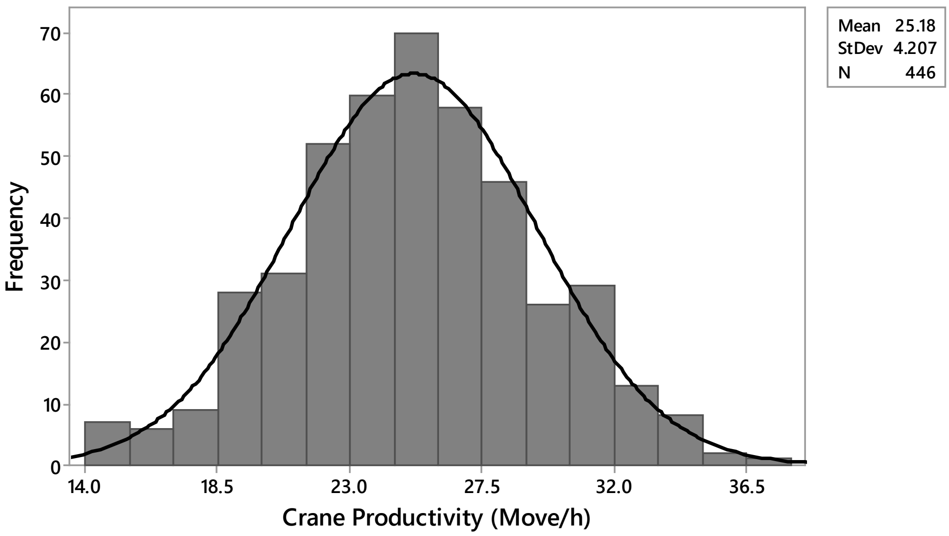


Figure 10. Histogram and normal distribution of crane productivity, where the productivities of Crane 2, Crane 3 and Crane 4 were considered.

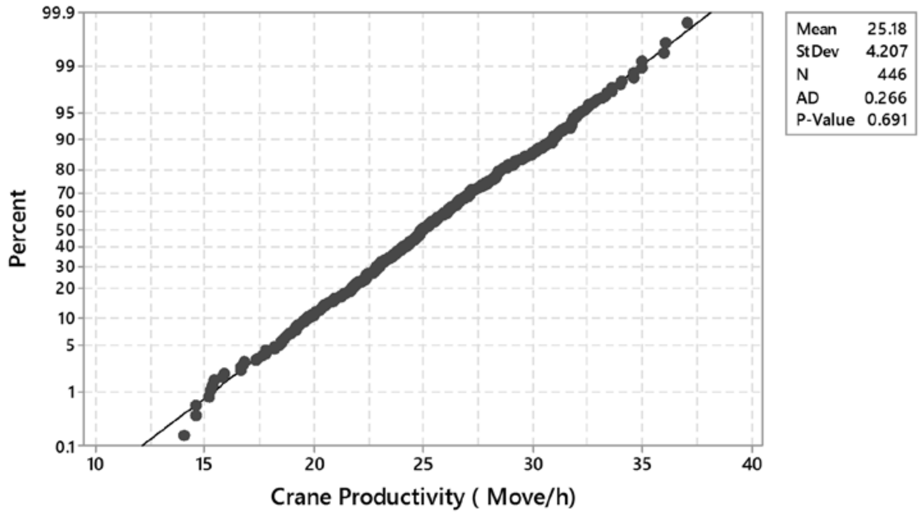


Figure 11. Anderson-Darling normality test plot, where the normality of the distribution is proven with P-Value>0.5 .

Finally, Anderson-Darling normality test is applied. Figure 11 shows the probability plot of the distribution. According to test result, P-Value is calculated as 0.691, which proves that the data fits well on the normal distribution [22].

3.3. Analysis of Operation Delays

Delays in a container terminal can be described as the idle times where the crane is not operating. Delays are most important factors which affects gross crane productivity. In the container terminal, all the delays caused by different reasons are recorded by terminal under following titles:

- Delays due to waiting for truck to unload the cargo from the crane's spreader,
- Delays due to waiting for truck to be taken by spreader to load on ship,
- Delays due to defect of spreader,
- Delays due to defect of crane,
- Delays due to ship passage,
- Delays due to putting/removing Out of Gauge (OOG) cargo device onto spreader (for containers with special dimensions)
- Delays due to manoeuvring of crane,
- Delays due to waiting for safety inspections,
- Delays due to bad weather conditions,
- Delays due to accidents, etc.

However, during the crane productivity calculations, not all the idle times are considered as delays, according to Brazilian Association of Public Use of Container Terminals rules (ABRATEC), which will be discussed on chapter 3.3. Therfore, it is decided to group the delays in three main categories:

- Delays due to Truck and Container Waiting,
- Delay due to Defect of Crane or Spreader,
- Other Delays.

In the data recorded by the terminal, it is given the sum of each specific delay occurred during one operation of ship. There is no information given regarding to the frequency or duration of these delays happen during one operation. If -for example- ”Delay due to Truck and Container Waiting” happens multiple times during one ship berthing; it is only known the total time of ”Delay due to Truck and Container Waiting”.

To be able to implement such delays in the simulation software, distributions of these delay groups should be introduced into the simulation. In order to create these distributions, it is decided to calculate average delays for each ship operation. For all of the ship operations, the number of cranes used, the total number of containers handled and total duration of these delay groups are available. It has been decided to apply these delays just before the spreader engages and disengages every single container, which is the most convenient way to implement delays in the simulation software.

Therefore, three different distributions belong to each delay groups are created, where all of them has total of 197 samples, which is the total number of ship berthing case studied.

Distributions are created by using Minitab software. For each class of delays, different histograms are created. In order to determine the type and specification of distributions, individual distribution identification is executed by using the same software.

All the distributions suggested by the software are not applicable, for the reason that they are not pre-defined in simulation software. Thus, the best fitting distribution is choosen which is available to introduce in simulation software.

Delays due to Truck and Container Waiting

This group of delays are caused by the interface efficiency of the container terminals[4]. These delays occur if an empty trailer arrives late during an unloading operation from ship to trailer (delays due to truck); as well as a trailer with a container arrives late during a loading operation to the ship (delays due to container). The probability of occurrence of such kind of delays depends on the number of cranes used in the operation, crane work loads, traffic congestion, and several managing problems [24]. Figure 12 shows the histogram and distribution of this class of delays.

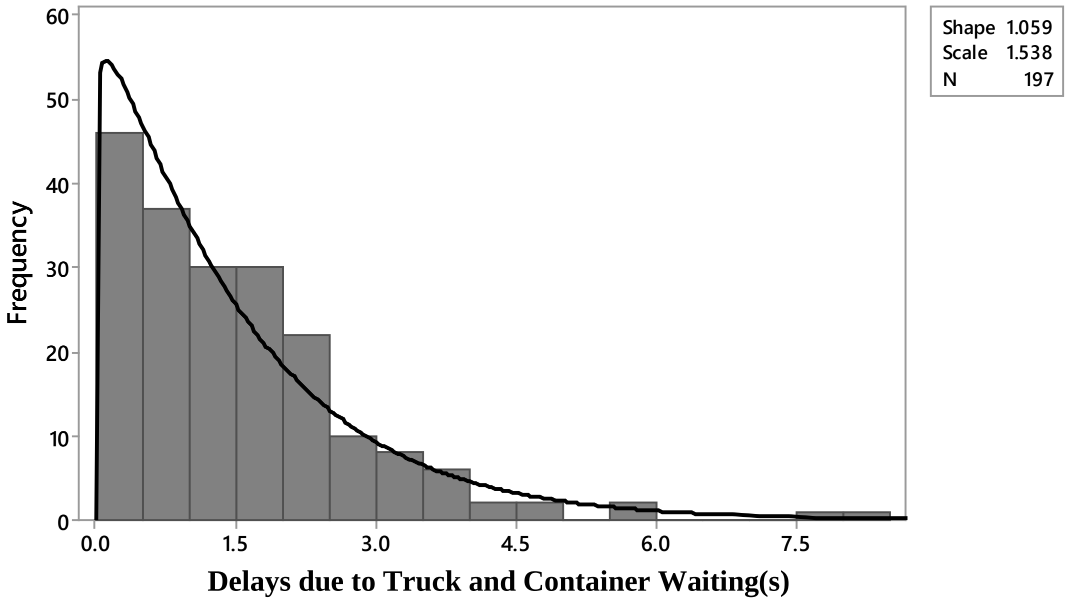
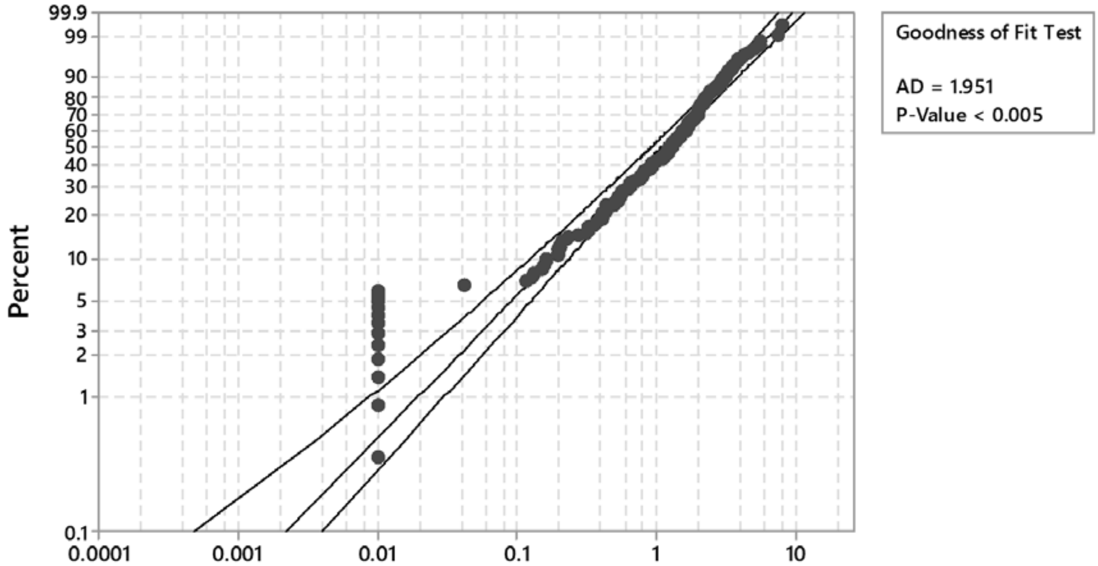


Figure 12. Waiting for Truck and Cargo Histogram and Weibull Distribution with 1.059 shape and 1.538 scale.

The distribution is determined as two parameter Weibull, with shape of 1.059 and scale of 1.538. The unit of histogram defined as seconds and it is made by 0.5 seconds of intervals.

In some of the operations, the waiting times are seen as zero seconds, which means there are no delays occur during these operations. However, to define a distribution in simulation software, it is unacceptable to define a zero seconds waiting time for a 2-parameter distribution. Hence, a simplification is made by shifting all zero values to a very small time decimal as 0.01s. The repeating points on Figure 13 caused by this translation.

[4] Stated by Mr. Daniel Oliveria at the terminal meeting on 03.10.2014

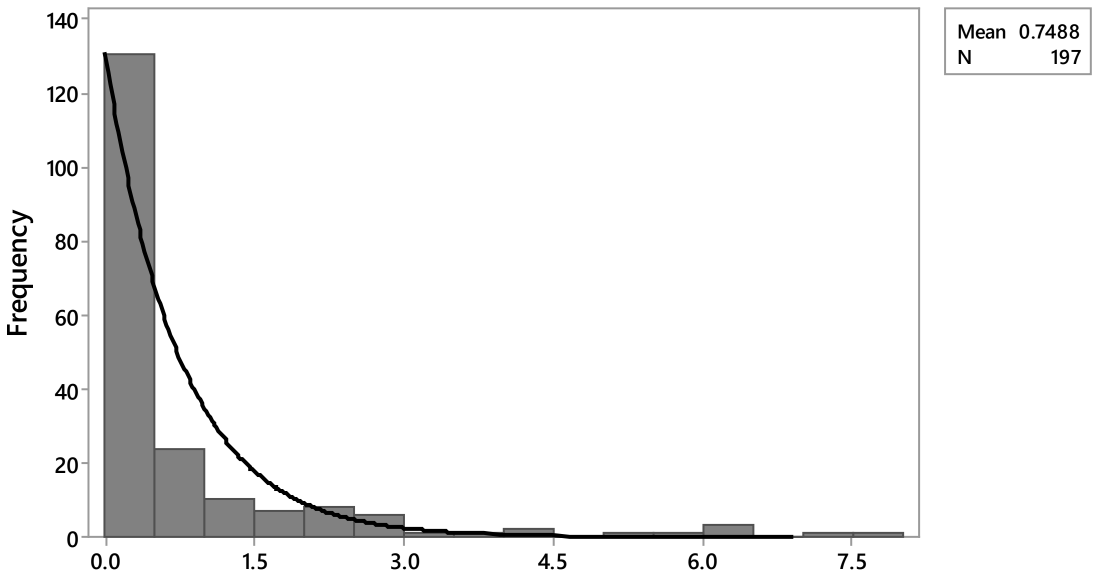


Delays due to Truck and Container Waiting – Treshold

Figure 13. Distribution fit of Waiting for Truck and Cargo with 95% of confidence level

It can be seen that the data provided does not satisfy the distribution entirely, because of zero values. It can be also predicted from the p-Value, which is smaller than 0.005 value. However, it is assumed to fit on the distribution and it has been used in the simulation.

Delays due to Defect of Crane or Spreader



Delays due to Defect of Crane or Spreader (s)

Figure 14. Delays due to Crane or Spreader Defect Histogram and Exponential Distribution with mean of 0.7488.

Procedures mentioned on the previous section of delays are applied onto the histogram of delays due to crane or spreader defects and it is presented on Figure 14. The best fitting distribution is observed as exponential distribution among the others. The distribution is set with 0.7488 mean value as it can be seen in the legend.

Delays due to Other Reasons

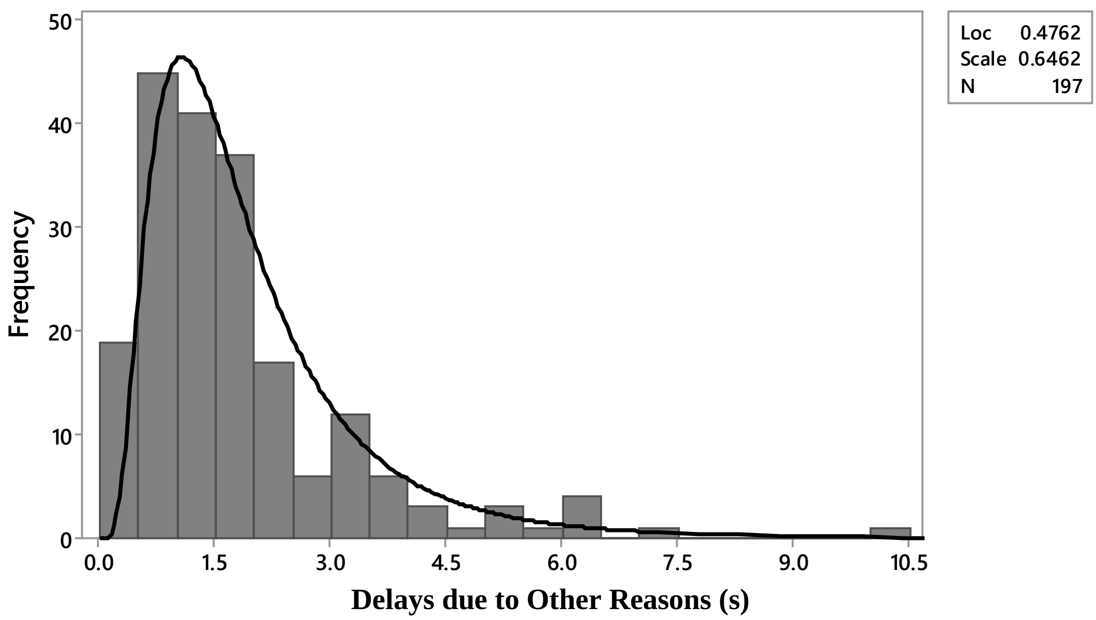


Figure 15. Delays due to Other Waiting Reasons Histogram and Lognormal Distribution with location 0.462 and scale 0.6462

As it is mentioned before, there are some other factors affecting the total berthing time, however they are not considered as delays in terms of crane productivity calculations. This delay distribution is computed as lognormal distributions as it is shown in Figure 15. Delays due to ship passage, putting/removing OOG cargo device, due to manoeuvring of crane, due to waiting for safety inspections, due to bad weather conditions and due to accidents are added in this distribution.

3.4. Input Data Modelling: Bay Plan and Stowage Condition

The input data which contains the new bay plan and a specific stowage condition is obtained from Harries. One of the container ship studied at his research is obtained from him and implemented into the simulation model. Input data creation process is explained by Harries et.

al. [5] with details. In this section, this process is explained shortly and it is mainly focused on how the data is fulfilled into our simulation model.

From an operational point of view, a container ship can be assumed as a three-dimensional grid of potential container slots [23]. Similar to a real container ship, the grid originates from bays (longitudinal axis), rows (transversal axis) and tiers (vertical axis). This 3D matrix is decided to represent by numerical values and *i*, *j* and *k* counters. Each slot has an id, consist of these *i*, *j* and *k* values. For example, a slot which is on 3rd bay, 2nd row and 4th tier is represented as "$f_{3,2,4}$".

During the mapping process of available slots of a bay plan, some of the slots are eliminated. Such as, slots mapped outside of the hull form, deck house and bridge, machinery room, hatch covers. During the creation process of a bay plan, those slots are ignored for container transportation and represented as "-1" in the input data. The slots, which are empty but able to stock a container, are represented with "0". Similarly, the slots which contain a container which should not be unloaded are symbolized with "1" and with orange colour, the slots contain a container which should be unloaded as "2" and with green colour and finally the slots contain a container which should be relocated due to hatch as "3" and with a blue colour. This configuration is summarized in Table 1. Figure 16 presents the profile view of a container ship with unavailable slots in grey colour and the other slots with a colour represented its' operational situation.

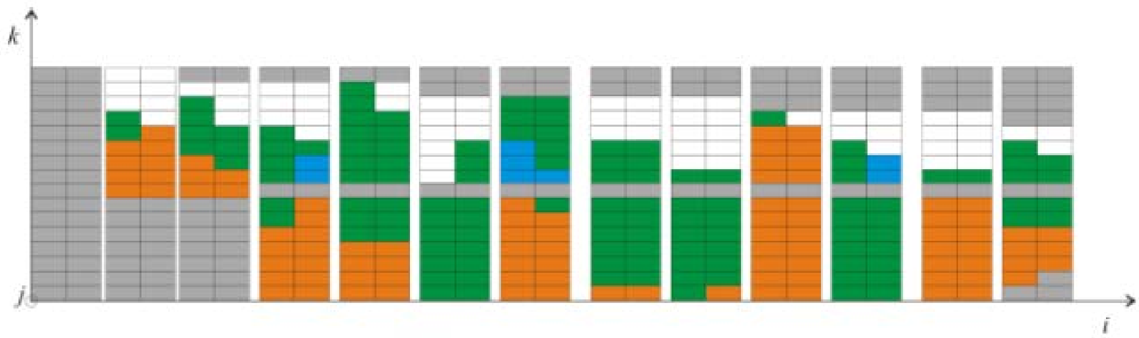


Figure 16. Side view example of a container ship with ignored slots (grey), containers to be left (orange), containers to be moved (green) and containers to be relocated(blue) [5].

Table 1. State identifier for each slot in container grid [5].

Identifier	Processing of container slot	Color of slot
$f_{ijk} = -1$	Not available for container storage	Gray
$f_{ijk} = 0$	Empty slot at given point in time	White
$f_{ijk} = 1$	Container to be left untouched (not handled)	Orange
$f_{ijk} = 2$	Container to be moved	Green
$f_{ijk} = 3$	Container to be moved off and on due to hatch	Blue

In this thesis, a 4250 TEU Panamax container ship is studied, where 2196 TEU to be left, 1200 TEU to be moved and 92 TEU to be moved off and on, due to hatch. Ship contents 17 bays, 13 rows and 14 tiers.

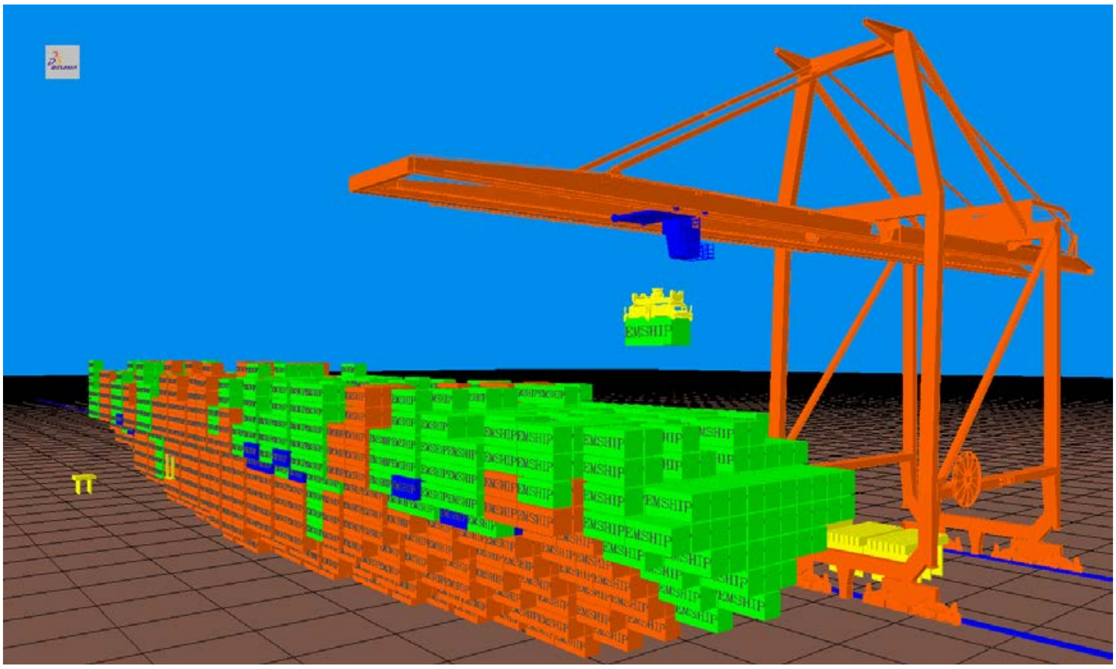


Figure 17. A view from the „Reference Case" of the simulation, where single crane operates and all TEU containers.

Figure 17 demonstrates a view from our simulation model. The hull of the ship is not added to be able to see the containers below hatch. In the case simulated, single crane is used and only TEU containers are implemented (See Case 1 on Chapter 4.6). The containers to be left (orange), to be handled (green) and to be re-handled (blue) can be seen.

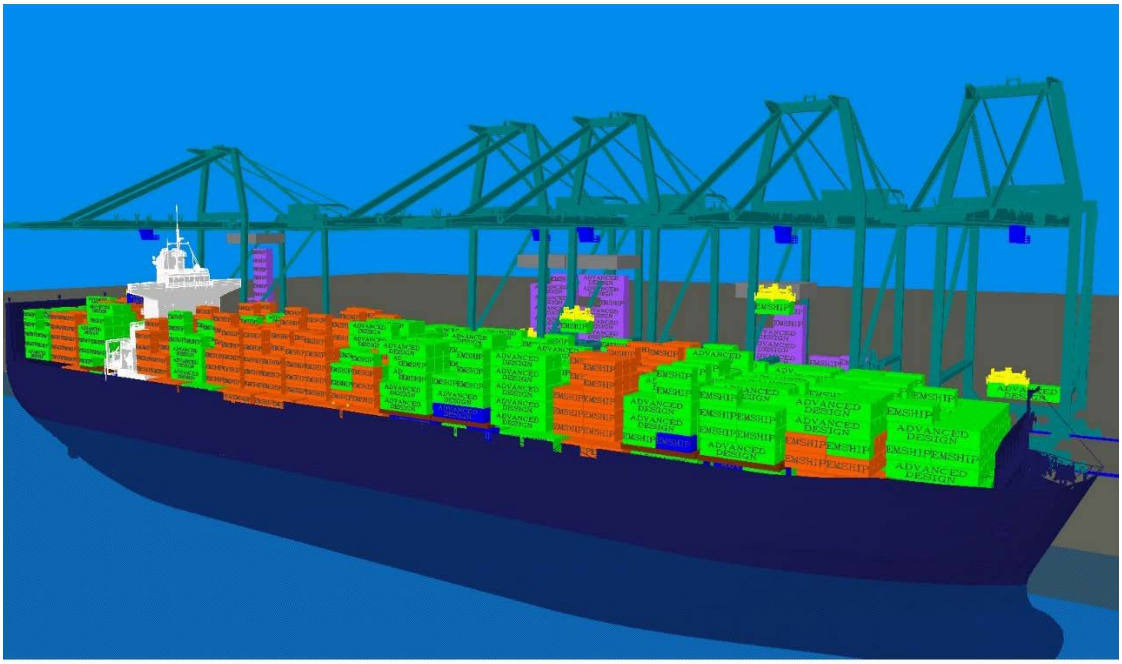


Figure 18. A view from simulation, FEU Implemented Case with 5 crane operation. Containers to be re-loaded on board can be seen in purple colour on the port.

As it is displayed on Figure 18, FEU containers are also added into the simulation as an improvement. (See Chapter 4.3.2) Thus, the input data for FEU containers should be represented as well. Therefore, new parameters are defined as in Table 2.

Table 2. Additional identifiers to define FEU case.

Identifier	Processing of Container Slot	Colour of Container
$F_{ijk}=4$	FEU to be unloaded	Green
$F_{ijk}=5$	FEU to be loaded	Purple
$F_{ijk}=6$	FEU to be relocated due to hatch	Green(on ship)/Purple(on port)
$F_{ijk}=7$	TEU to be unloaded/FEU to be loaded	Blue/Purple
$F_{ijk}=8$	FEU to be unloaded/TEU to be loaded	Blue/Purple
$F_{ijk}=9$	TEU to be loaded	Purple

All TEU Containers are labelled as ”EMSHIP” and all FEU containers are labelled as ”Advenced Design” to be recognized during the simulation animation. Figure 19 states the containers located on hatch covers of the ship.

The colours used in the simulation have another important signification. The crane logic for different kind of operations is programmed according to the colour of containers. In the simulation, the crane is able to recognize different colours and decide to perform the type of operation: If the container is orange, crane does nothing, if the container is green or blue, crane unloads the container from ship to shore; if it is purple, crane loads the container shore to ship. It is not possible to define the same colour for the same kind of operation, even if the containers are the same. Therefore, the re-handled containers and loaded containers are needed to be defined with a different colour. Because of the same reason, the hatch covers to be unloaded are assigned as brown and hatch covers to be loaded are assigned as grey.

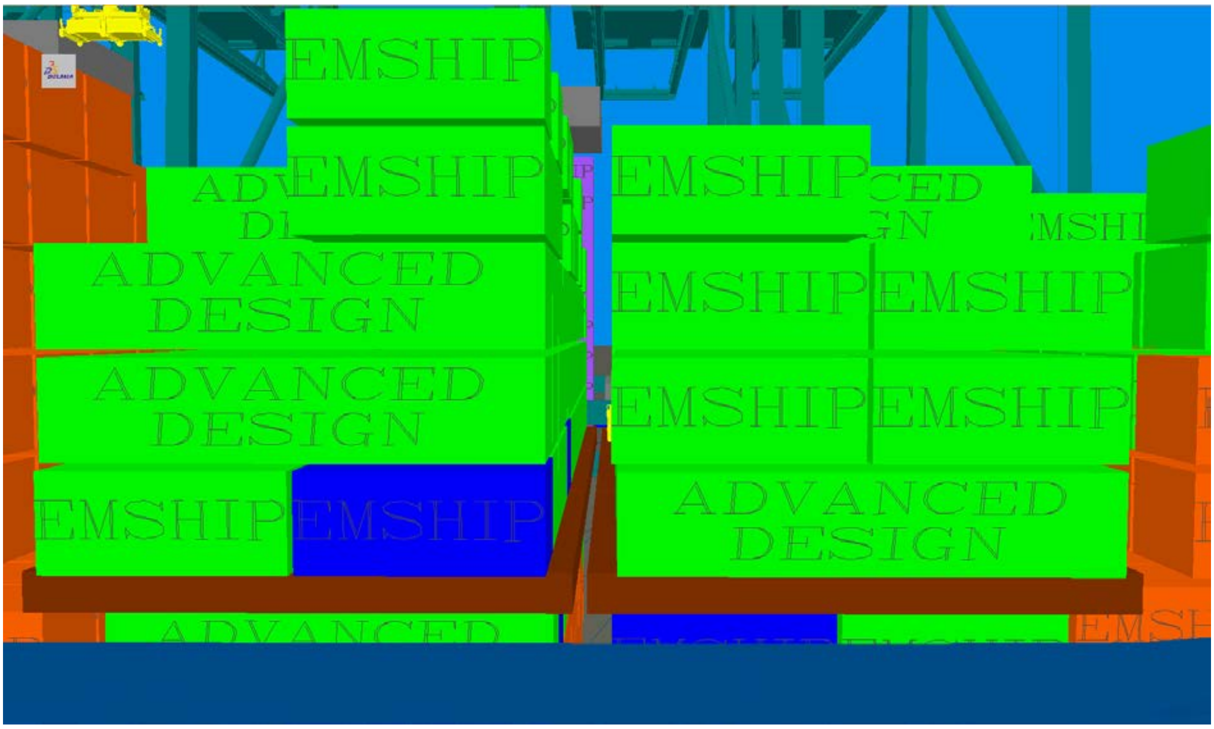


Figure 19. A view from Case 3, where FEU implementation is performed. Containers located on the hatch cover of the ship.

4. SIMULATION

4.1. Structure of the Research

This study clusters information and data from different professionals of maritime sector and this cooperation is mentioned by giving references in different sections of the thesis. In order to present the big picture to the reader, this section is dedicated to explain the structure of the research done. Figure 20 states this association schematically.

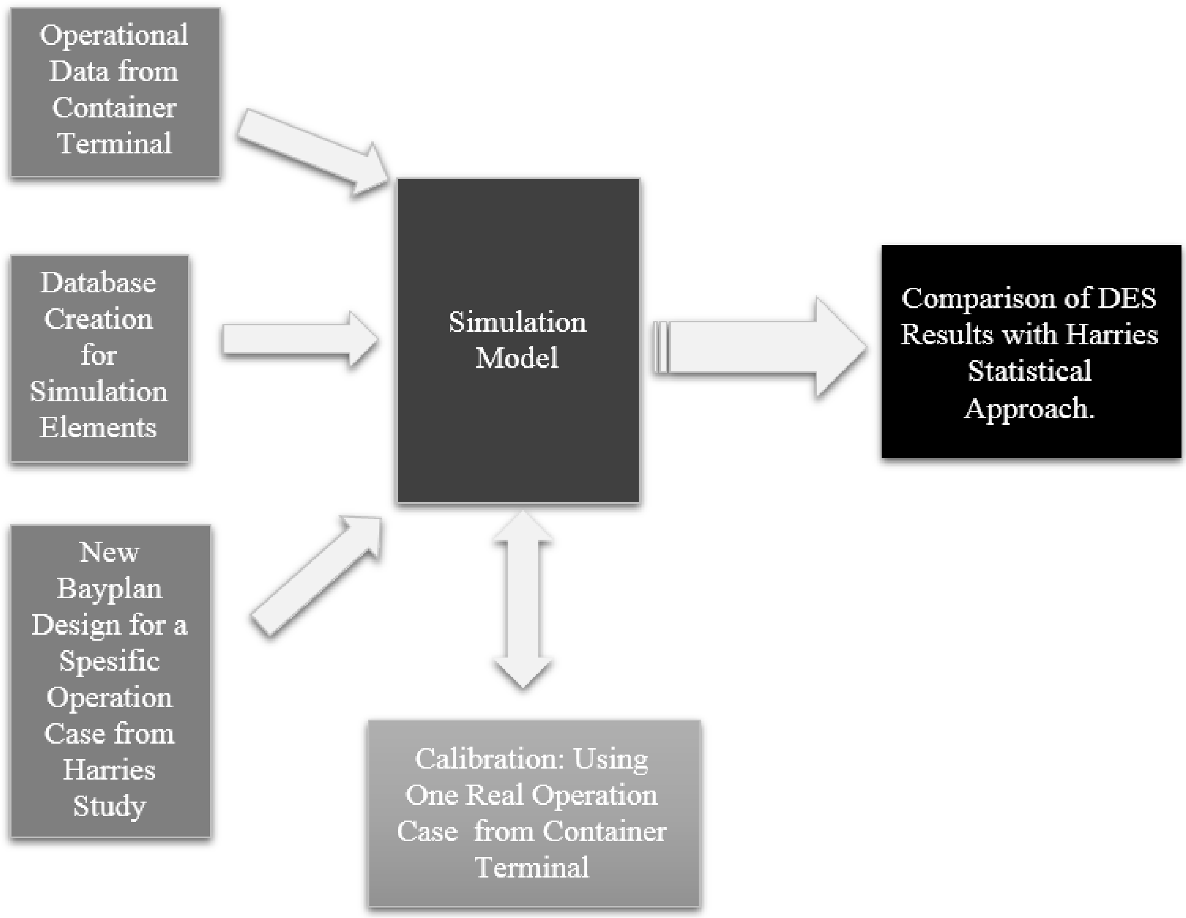


Figure 20. Structure of the Research

Database creation for the simulation elements is one of the main branch of this study, a fully parametrical model is developed, which will be explained with details on chapter 4.2.

During database creation process, several meetings were arranged at Libra Container Terminal, as it was explained on the last paragraph of chapter 3.2.

As the third main branch that composes the simulation model, the new bay plan design and pre-planned realistic stowage case are implemented, which were used in the paper of Harries et. al. [5]. Several online meetings were organized about progress and achievements of this further research.

After simulation model is entirely created, it is calibrated by performing a simulation of one real operational case executed in Libra Container Terminal, with one ship which is one the most frequent in terminal and one of the most similar ship to the simulation case. The results of simulation and the real operation reports are compared to reach the aim: Completely calibrated simulation model.

As the last step, the simulation cases are defined and simulations are operated to gain the results.

4.2. Creation of Simulation Model

The simulation model is created with DES software ”QUEST” which is a powerful product of Dassault Systems. In order to provide a clear perception, the elements of the simulation model are explained briefly in this chapter.

QUEST allows users to work on Graphical User Interface (GUI), in order to build the simulation model. This feature provides the user to design and visualize the 3D animation of the model itself. One of the most important advantage of this aspect is to aid user to follow the work on process, check potential errors regarding to simulation visually. During this project, the crane movements, crane timing, delays, positions of cranes and crane equipment’s, position of containers, container slots, crane allocation for multiple crane cases etc. are initially checked from GUI.

Furthermore, it provides a decent way of explaining the work behind the simulation by recording movies and capturing screen shots from the simulation phases. GUI can be used for basic simulation models to be formed. However, it is not practical and it does not allow user to define advanced spesification’s to adjust in exceptional cases. Moreover, enormous amount of data should be implemented into the simulation and it is not practically feasible to do by using GUI. Hence, the whole simulation model is generated by using Simulation Control Language (SCL).

SCL is the procedural language of QUEST which lets user to construct logic to manage the actions and behaviours of all the properties of the simulation model. The term “logic” can be expressed as the decision-making activities that happen at certain times during the simulation. Such as, commanding to a crane to move another bay after all the containers are handled in the current bay can be defined as a ‘logic’.

Even though there are some existing logics as built-in the software, for this specific simulation case, some new logics are defined. On the other hand, various Batch Control Language (BCL) commands are used in these SCL files. BCL commands are used to create new elements, define features of created elements or change these features. For example, a crane can be created, all specifications can be defined (speeds, accelerations, dimensions, colours) by using its data file, and it can be even changed before or during simulation process.

The entire simulation model is created parametrically. As it is schematized on Figure 21, the model contents different modules concerning the different properties of simulation. This structure can be compared with "Lego" blocks in terms of functionality; they can be removed, changed, new features can be added according to the need of user for the simulation case.

The setup of entire simulation model in the software is designed to load with only one user-defined button. This one-button-triggered creation process takes less than 3 minutes for the main study case with Intel i7-3630CM 2.4 GHz GPU 12 GB RAM.

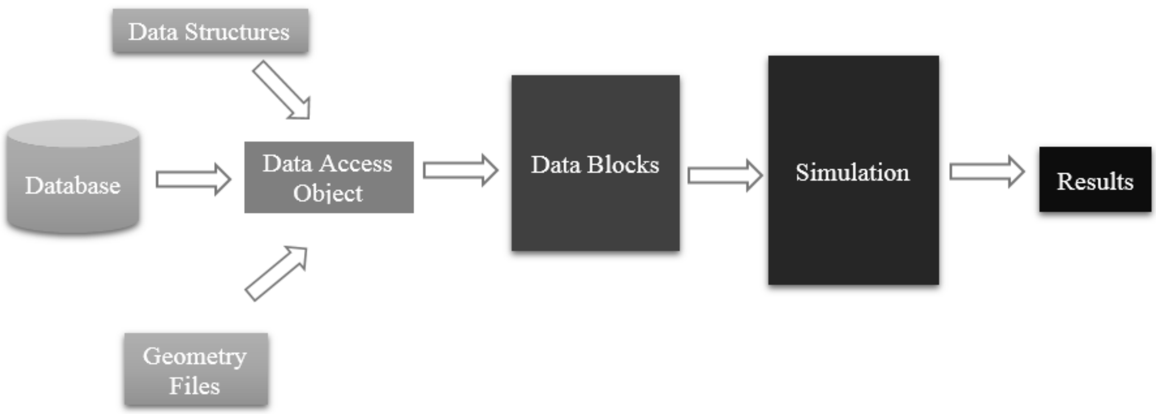


Figure 21. The structure of the Simulation Model

a. Database

Database contains the data files to define all numerical and physical properties of elements used in the simulation. Data files are in the *csv file format (comma-separated values) which can be basically defined as Excel files contains different specifications for different types of data.

Essentially six data files are created for the simulation: Containers, Arrival Condition, Bayplan, Stowing Schedule, Cranes and Objects.

Containers: Includes the container ID, colour, type (FEU/TEU), specification of good inside containers (normal, dangerous, reefer) etc. features of all the containers handled in the simulation. Hatch covers are also implemented into this file, because they are treated as containers for both creation and handling processes. This file is used to create all the containers and hatch covers used in the simulation.

Arrival Condition: Includes the container ID, bay, row, tier number of the containers which exist on board of ship in the beginning of simulation.

Bayplan: Includes x, y, z coordinates and i, j, k identification of each container slot; and bay, row, tier number correspond to these coordinates. It contains also information about availability of slots for reefer, dangerous cargo, special size/type of cargo etc. However, special type of cargoes were not considered in the simulation. This file is used to create the container slots of ship.

Stowing Schedule: Includes container ID, container handling sequence, bay, row, tier number of container. This file is used to organize the operation sequence about which container is going to be handled and when.

Cranes: Incorporates various specification's about cranes used in the simulation: Speeds, accelerations, dimensions, initial positions, working positions of crane, hoist and spreader, dimensions and locations of crane tracks etc. Moreover, crane allocation for different bays is made through this file.

Objects: This file includes data regarding to simulation elements, such as the ship, where all the containers are located and trailers, where containers are unloaded.

b. Data Structures

Data structures are the files which brings simplicity into the coding process. In order to define each column of each data file, an individual data structure is created. Data structures are *inc files (include) which can be called into the Data Access Objects (DAO)'s by their names and save the user to define all the parameters once again.

c. Geometry Files

Geometry files are the files to define 3D models of simulation elements. Crane, hoist, spreader, TEU and FEU containers, trailers on shore are the main 3D geometries used in the simulation animation.

d. Data Access Objects (DAO)

DAO’s can be described as the tools for the simulation to read and employ data into model. They are created for each data file used in the simulation model.

e. Data Blocks

It can be said that the Data Blocks are the files which contains each kind of logic of the corresponding element. In data blocks, user can define tasks and functions, and when, how, where to apply these functions. In this simulation, mainly two data blocks are used: For source and cranes.

Source is an element of simulation which is responsible of creating the containers and hatch covers and place them into their initial location before simulation starts.

Cranes, on the other hand, requires more arduous solutions for this complicated simulation case. Cranes are the most convoluted and specific elements of this simulation case, as it is for a real container terminal operation. Hence, a special attention is paid during creation and definition of logics of cranes. Here are some of the main important features applied into Crane data block:

- Distributions of delays are introduced into the Crane Data Block. Each time when the crane spreader engages or disengages to a container, one different value is attended from all 3 types of distribution (see chapter 3.3) randomly and let the crane wait for a spesific time. This procedure is repeated for all the containers in the simulation, for each engaging and disengaging during a handling process.
- Simulation duration and delay times are recorded by the help of some codes written into Crane Data Block. The operational time of crane is started when the first container is taken on board of ship until the last container is landed onto the trailer for unloading case, or the other way around for loading case. In order to calculate the net operational time, total delay time for each container is summed up and removed from gross operational time. All these data is transferred into an Excel file by another set of codes.
- In Harries’ case, the spreader movements are separated as lifting up, translating, lifting down; and reverse for the rest of operation. However in reality, it can be seen during many operations that the spreader can be lifted up, during its translating process. This is a very complicated movement that should be managed and observed by the crane operator. In the simulation, this movement is implemented by considering absolute security concerns. This movement is sketched on the Figure 22.

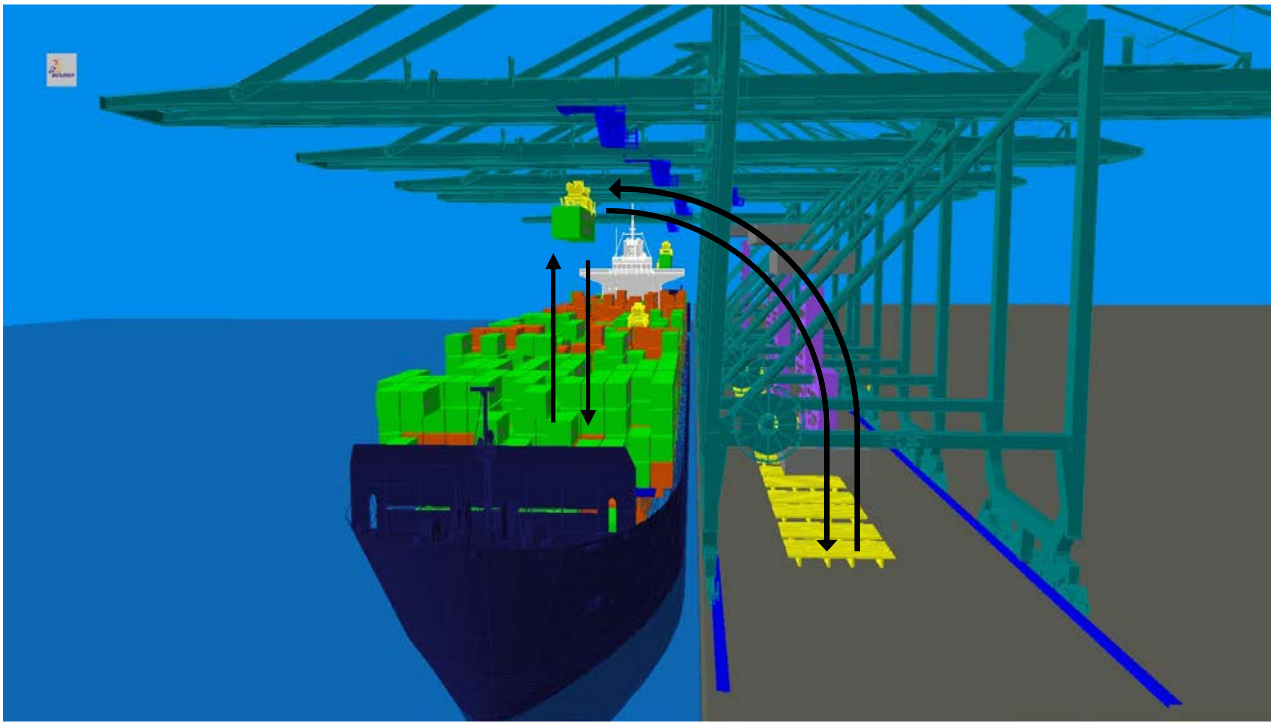


Figure 22. A front view from the simulation, during performing multiple crane operations, where curvy movement implementation for crane spreader is sketched.

This short-cut movement makes the operational time shorter in terminals, as well as in the simulation, which will be discussed in chapter 5.

4.3. Other Improvements

4.3.1. Hatch covers

Implementing hatch covers into the simulation is another improvement of the existing research. Hatch cover opening and closing operations are generally performed by the help of quay side cranes for Panamax size ships. They are basically handled with the spreader and they are located on the shore until the operation inside of hatches finishes[5]. In some sources, hatch cover handling time can be evaluated as a delay [24]. However, the rules of ABRATEC are followed to evaluate this operation. According to ABRATEC, each hatch cover handling process is counted as 1.5 crane movement, which is taken into account during crane productivity calculations. It will be explained with more details on chapter 4.4.

In the simulation of Harries et. al. [5], the hatch cover removal duration was taken constant as 900 seconds. However, with DES, it is possible to create hatch covers in the same manner of creating containers and to handle by crane. The ships examined through this research are

[5] Stated by Mr. Daniel Oliveira, Operation Manager of Libra Container Terminal on 03.10.2014

Panamax size container ships (3001-5100 TEU), hence during the design process of the hatch covers, this fact is taken into account. The hatch covers are designed as 40' length of bay, as reality. The hatch cover width of considered vessel can be seen in "Appendix I – Hatch cover design reference document" as between 7.48 meters to 13.63 meters. The hatch covers are designed for the bays where an operation under hatches will be performed. Considering the row number (for Harries' case 13) and the dimensions of hatch covers for similar beamed ships, it is decided that 3 hatch covers can be placed per bay by 10 meters of width.

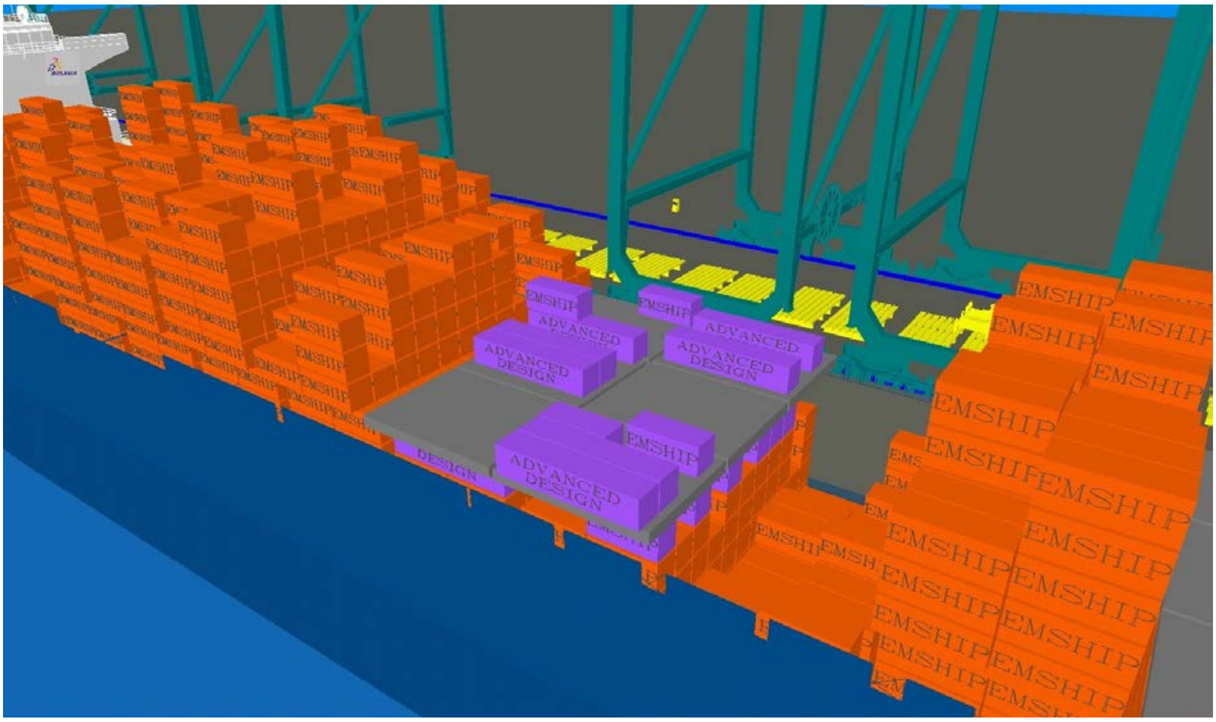


Figure 23. A view from the end of simulation, where multiple crane operations are performed. On board of ship, containers to be left (orange), re-handled containers (purple) and re-handled hatch covers (grey) can be seen.

In Figure 23, container ship can be observed at the end of operation after all the green and blue containers as well as brown hatch covers are unloaded; purple containers and grey hatch covers are re-handled.

4.3.2. FEU Implementation

As it was mentioned before, the study of Harries et. al. [5] was carried on only TEU containers and afterwards it was abstracted towards reasonable TEU to FEU ratios. According to the data obtained from Libra Container Terminal, this ratio is calculated and given on Figure 6 in section 3.2.

53% of the all handled containers are converted into FEU containers. Two TEU containers located in the same bay to be unloaded or two TEU containers to be loaded to the same bay are transformed into one FEU container, by using this ratio. The location of these containers are chosen randomly, however they are distributed as uniform as possible.

4.3.3. Trailer Height Adjustment

In earlier study, the containers are loaded and unloaded from the ground level. However, in reality the containers are loaded and unloaded from/to trailers. Hence, the buffer height of trailers are taken as 1.05m. [6], which can be observed in between 1m-1.6m in reality. In order to have more precise results, it is decided to employ this expansion into the simulation.

4.4. Crane Productivity Calculations

Crane productivity calculations are carried by taking ABRATEC as reference. Related pages of the reference paper can be seen in Appendix II – ABRATEC Crane Productivity Calculations.

Crane productivity can be distinguished in literature in two main ways: Gross crane productivity and net crane productivity.

Gross crane productivity is the total number of crane movements during total operational hour, between first and last lifting. It means that, the idle times are also counted in this calculation. To be more precise:

$$Gross\ Crane\ Productivity = \frac{TMC+TEHM+TEOM}{TOT} \tag{1}$$

Where:

- TMC: Total number of Movements of Containers,
- TEHM: Total Equivalent Hatch cover Movements,
- TEOM: Total Equivalent Out-of-Gauge Container Movements,
- TOT: Total Operational Time.

[6] The average height of container trailer height 1.00m-1.1m according to the meeting notes from Libra Container Terminal

As it was mentioned before, hatch cover implementation is one of the improvements performed in this simulation compared to Harries' study. Therefore, besides total movement of containers, total equivalent hatch cover movements are also calculated.

$$TEHM = HM \times CI \tag{2}$$

Where:

- HM: Total number of Hatch covers Moved,
- CI: Conversation Index.

CI for hatch covers are given as 1.5 by ABRATEC. It means, if three hatch covers are loaded and unloaded during and operation, 3x2x1,5=9 total equivalent crane move is done.
Total equivalent Out-of-Gauge Container Movements are calculated similarly with a conversation index of 4, yet during the simulation and calibration OOG containers are not used. So TEOM can be ignored.
On the other hand, net crane productivity can be described as the total number of crane movements during net operational time. In ABRATEC, it is stated as following:

$$Net\ Crane\ Productivity = \frac{TMC+TEHM+TEOM}{TEOT} \tag{3}$$

Where:

- TEOT: Total Effective Operational Time.

Total effective operational time can be described as total operational time except the idle times per crane. It can be also expressed as following formula:

$$\mathrm{TEOT} = (\mathrm{Total\ Operational\ Time}) - \frac{\mathrm{All\ Cranes'}\,Total\ Idle\ Time}{\mathrm{Total\ Number\ of\ Cranes\ used\ in\ Operation}} \tag{4}$$

4.5. Simulation Calibration

Simulation calibration is a vital process to secure the reliability of the simulation. Therefore, a simulation case is created according to the report of an operation carried out at Libra Container Terminal. The report contains information about the containers to be unloaded and the containers to be loaded, the sequence of operation, crane allocation for bays, shifts, total operation times of cranes, delays together with the summary of the cranes and overall operation. Below, some specifications are presented regarding the inspected operation:

- Ship name: Hyundai Platinum,
- Capacity: 5000 TEU,
- Total Loaded: 120,
- Total Unloaded: 624,
- Hatch Covers Handled: 18,
- Grand Total Moves: 774,
- Operation Start: 13.09.2014 11:20,
- Operation End: 13.09.2014 21:08.

Following the full operational report, all the containers and hatch covers to be loaded and unloaded, the simulation model was created. In ”Appendix III – The Summary of Report for the Operation to Calibrate the Simulation”, pages relating to the summary of this operation, one ship discharge detail sheet and one crane work list sheet are added to give the reader an idea about a container terminal operation report. Three cranes were allocated for this operation and similarly, three cranes are created for calibration model. All of the aforementioned cranes are allocated for the same bays as in real operation case.

For this operation, Crane 1, Crane 2 and 3 are allocated (see Figure 3). Upon the investigation of the operation report, it can be seen that the crane allocation is done unevenly: Crane 1 performs 164 moves ; Crane 2 and crane 3 are assigned to perform 305 moves. Nevertheless, Crane 1 identifies the time the ship needs to stay at port due to the longest operational time. During an operation planning of a container terminal, crane moves are generally distributed evenly, unless the cranes are unequal[7]. This inequality is demonstrated in Figure 9, therefore Crane 1 was declared as an outlier. Recalling that the aim of the study is not to replicate a

[7] Operation Manager of Libra Container Terminal Mr. Daniel Oliveria stated at the terminal meeting on 03.10.2014.

container terminal but to extract general behaviours of a terminal in order to examine the performance of a new bay plan design, Crane 1 is not used for the calibration case.

First, simulation was run for several times to ensure the equality of average net operational time of two cranes, in simulation and in reality. During calculation of net operational time of the simulation, delays are not applied, which means that there is no stochastic variable applied into the simulation. Therefore, the same results were obtained for each iteration, unless crane speeds and accelerations were altered.

To identify crane speeds and accelerations which would provide same average net operational time as in real case, several iterations were run. Finally, following values are obtained:

- Hoist Speed: 2,94 m/s,
- Hook Speed: 0,938 m/s,
- Crane Speed: 0.114 m/s,
- Crane Acceleration: 0.1 m/s^2.

Subsequently, the delays were defined as explained in chapter 3.3 and the simulation was run for 400 iterations.

Table 3 presents the comparison of net/total operational time, net/gross crane productivities, total number of crane moves for the real operation case and simulation:

Table 3. Simulation Calibration Result & Operation Report Comparison Table, where Total and Net Operational Times, Total Crane Moves, Gross and Net Crane Productivities are presented.

Calibration		Total Operational Time (hh:mm)	Net Operational Time (hh:mm)	Total Crane Moves	Gross Crane Productivity (Move/hour)	Net Crane Productivity (Move/hour)
Operation Report	Crane 1	09:48	07:59	164	16.73	20.54
	Crane 2	09:11	08:42	305	33.21	35.06
	Crane 3	08:01	07:32	305	38.05	40.49
	Crane 2&3 Average	08:36	**08:07**	305	35.63	37.78
Simulation Calibration Result	Crane 1	04:23	04:13	164	37.44	38.96
	Crane 2	08:20	08:00	305	36.65	38.10
	Crane 3	08:34	08:14	305	35.59	37.06
	Crane 2&3 Average	08:27	**08:07**	305	36.12	37.58

*Standard deviations for Crane 1, 2, and 3 are 20 , 27 and 29 seconds, respectively.

In order to calculate the total operational time, accumulative avegare of 400 iterations was calculated. It can be seen that simulation results for Crane 1 are dramatically lower than the real case, which confirms the reason for distinguishing it as an outlier more clearly. The average of net operational time of Crane 2 and Crane 3 was calculated as 8 hours and 27 minutes, which is only 8 minutes different from the average operational time of Crane 2 and Crane 3. Regarding these results, it can be stated that the simulation was calibrated.

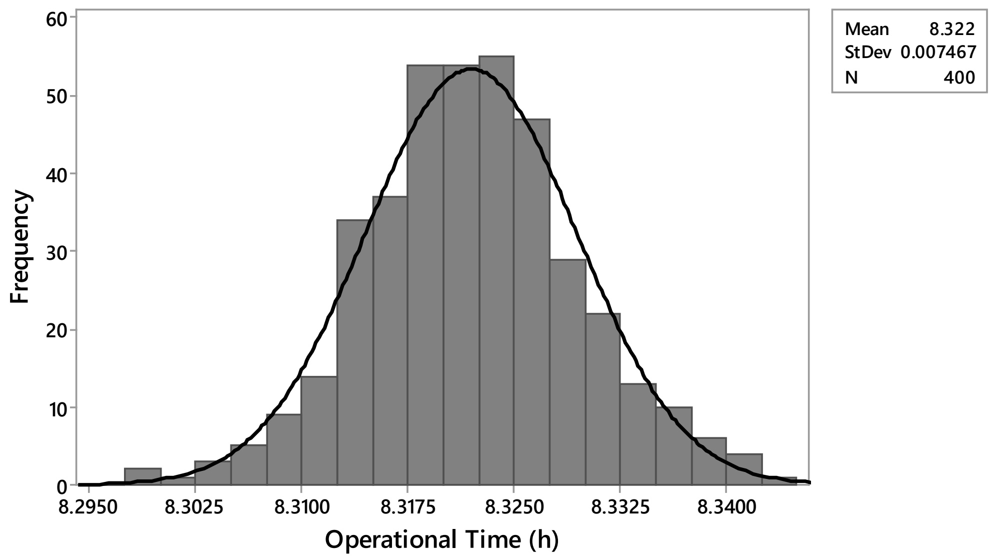


Figure 24. Histogram and Normal Distribution of Results of 400 Iterations of Crane 2, where mean is calculated as 8.322 hours with 0.0075 standard deviation.

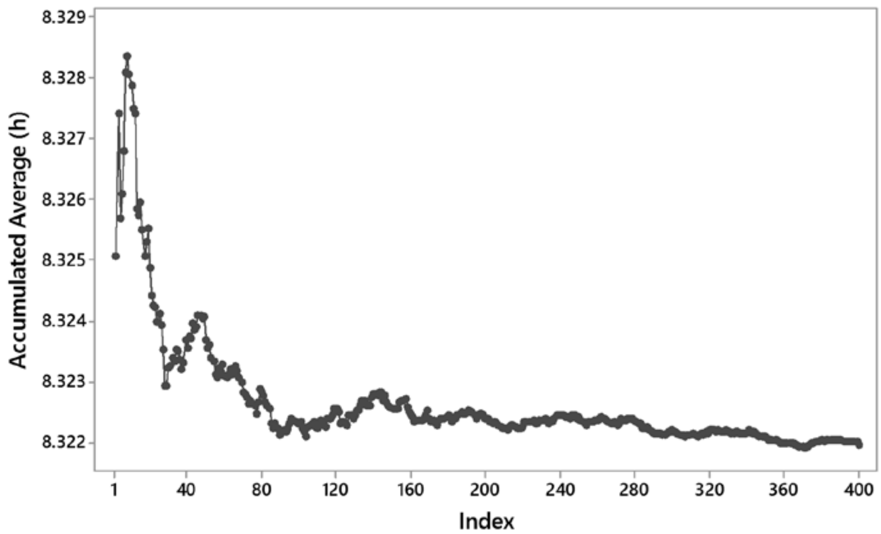


Figure 25. Convergence Plot of Accumulated Average of Total Operational Time

Figure 24 shows the histogram of total operational time results of crane 2. As it was expected, the results are showing a normality behaviour. As a result, total operational time of Crane 2 is calculated as 8.322 hours, which corresponds to 8 hours 20 minutes. The standard deviation is calculated as 0.0075 hours, which is equivalent to 27 seconds.

The plot of convergence is presented in the Figure 25 and as it can be seen from the graph all simulation cases were run for 400 iterations during this research.

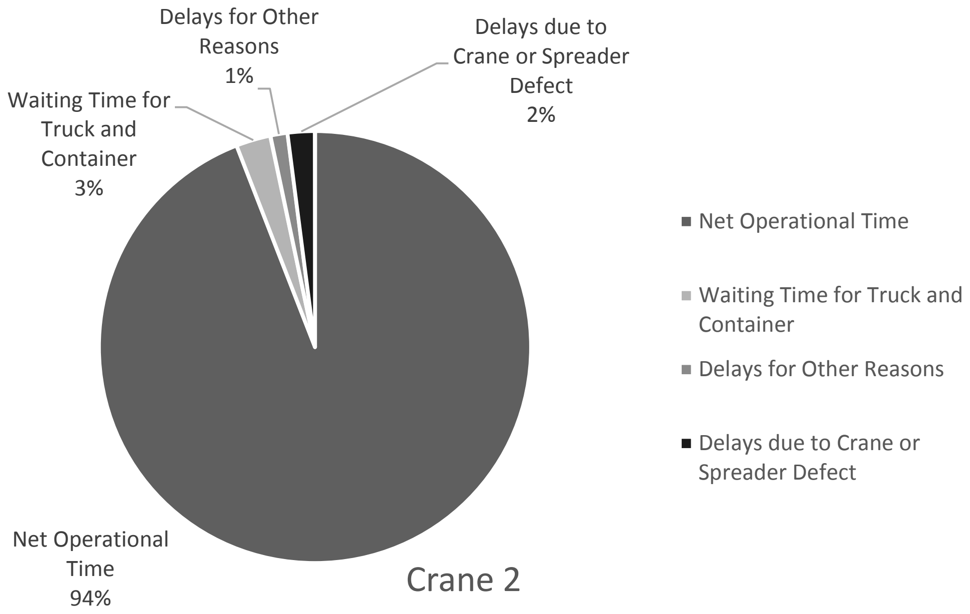


Figure 26. Pie Chart of Net Operational Times&Delays of Crane 2, where Net Operational Time is 94%, waiting for Truck and Containers is 3%, Delays due to Crane or Spreader Defect is 2% and Delays due to Other Reasons is 1% of all operational time.

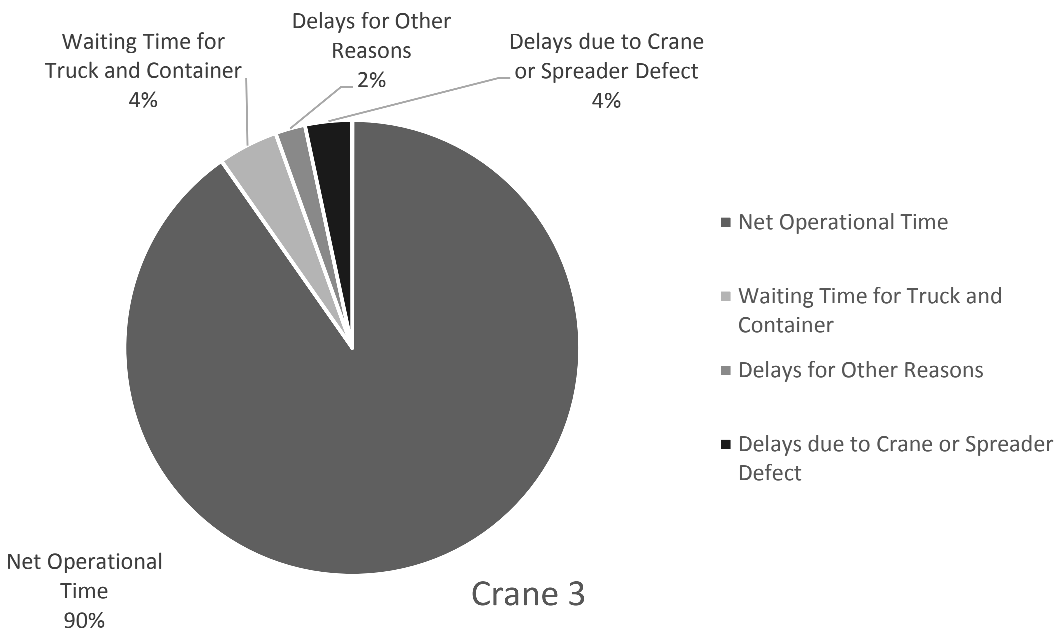


Figure 27. Pie Chart of Net Operational Times&Delays of Crane 3, where Net Operational Time is 90%, waiting for Truck and Containers is 4%, Delays due to Crane or Spreader Defect is 4% and Delays due to Other Reasons is 2% of all operational time.

In Figure 26 and Figure 27, pie charts depicting operational times of Crane 2 and Crane 3, which were used in the simulation, are demonstrated. ”Waiting Time for Truck and Container” is calculated as 3% and 4% respectively. According to the declaration of Libra Container Terminal[8], waiting time for truck takes 1% and waiting time for container takes 3% of average total operational time on port. Having obtained very similar results from the simulation confirms that the distributions are well defined and guarantees that the results are very close to reality.

4.6. Simulation Cases

After the calibration process, the simulation cases are defined as follows:

- Case 1: Some physical changes made on the port and on cranes are compared.
- Case 2: Focuses on the effect of multiple cranes.
- Case 3: FEU involved stowage circumstance with using multiple cranes.

In this section, the model mentioned in chapter 3.4 was used. A Panamax container ship which with the capacity of 4250 TEU was examined. For the cases where only TEU containers are considered; 1200 TEU container unloaded, 92 TEU container re-handled (unloaded and loaded back due to hatch) and 15 hatch covers are unloaded&loaded back to the ship. For FEU cases, 53% of all containers were transformed to FEU and the hatch covers were added to be loaded&unloaded.

To make comparison with the results of statistical approach [5], same crane speeds were used and acceleration was implemented as following:

- Hoist Speed: 3 m/s,
- Hook Speed: 1 m/s,
- Crane Speed: 0.114 m/s, (corresponds to 2 min/bay),
- Crane Acceleration: 0.1 m/s^2.

[8] Stated by Operation Manager of Libra Container Terminal Mr. Daniel Oliveria at the terminal meeting on 03.10.2014.

Case 1: Examining Physical Changes and FEU Implemented Stowing Plan

In the first case, some possible physical changes in the terminal such as positive or negative change in the crane hoist and spreader speeds, high or low tide, are studied. Lastly, to compare with reality, FEU transmission was made and added to this case. Only one crane was used to perform this study.

The cases performed were:

- Reference case,
- +10% Speeds of Crane (will be referred to as +10% Speed),
- -10% Speeds of Crane (will be referred to as -10% Speed),
- High Tide (Ship is 0.5 m higher than main case),
- Low Tide (Ship is 0.5 m lower than main case),
- 53% FEU.

As a result of the statistical analysis of Libra Terminal, 53% of containers were transformed into FEU and distributed instead of TEU’s.

Case 2: Examining Multiple Number of Crane Usage on Port Efficiency

Case 2 is dedicated to examining the importance of the crane number for operational strategy. The cranes are allocated to different bays with the aim of performing similar numbers of moves during one operation. Total operational time is calculated according to the crane which finished its operation last. Up to five cranes were implemented.

The crane allocation was carried out by taking into account operational concerns and the similarity in number of moves performed by each crane. For this reason, different bays were assigned to each crane and operation was carried through the same direction, to prevent any collision. As an operational concern, at least one bay of distance is provided for all neighbouring cranes.

Case 3: Examining Multiple Number of Crane Usage on Port Efficiency of FEU Implemented Stowage Plan

Similar to Case 2, multiple cranes were devised and their performance on the 53% FEU implemented stowing plan was calculated.

5. RESULTS

Results obtained are presented under three main cases. Every simulation case presented before was run for 400 iterations and it was observed that all solutions reach convergence level. Different cases take different computational time depending on the number of cranes used and the number of the containers handled. One Crane simulation with all TEU containers was estimated as 2 hours and 48 minutes, while five cranes simulation with 53%FEU containers took only 17 minutes for 400 iterations with Intel i7-3630CM 2.4 GHz GPU 12 GB RAM.
All the time units are provided in hours, therefore, an operation which taking 20.5 hours can be translated into 20 hours and 30 minutes. In each simulation, operational time was calculated starting from the crane picking up the first container to handle until the last container to be handled is disengaged. In multiple crane operations, the operational time was defined according to the crane that had the longest operational time. All operational times used in the multiple crane simulations were compared and the operational time of the crane, which operated the longest, was taken as the Total Operational Time.

Case 1: Examining Physical Changes and FEU Implemented Stowing Plan

Table 4 states the simulation results for Case 1, wherein some physical changes on the system were examined. As it has been stated earlier, only one crane was used to perform analysis for Case 1. The table provides data regarding total operational time, total waiting time for truck and container, delays for other reasons, delays due to crane or spreader defect, total moves performed by crane, gross crane productivity and net crane productivity. In the first row, the main model used in the Harries' approach is reviewed as reference case. All time related results are given with its accumulated average of all iterations as well as its standard deviation.

Table 4. Case 1 Results on physical changes and FEU Implemented Stowing Plan, where μ represents mean, σ represents standard deviation.

Physical Changes Case	Total Opr. Time (h)		Net Opr. Time (h)	Waiting Time for Truck and Container (h)		Delays for Other Reasons (h)		Delays due to Crane or Spreader Defect (h)		Total Mov.	Gross Crane Prod. Move/h)	Net Crane Prod. (Move/h)
	μ	σ		μ	σ	μ	σ	μ	σ			
Ref. Case	44.000	0.0170	42.29	0.965	0.619	0.498	0.624	0.775	0.808	1428	32.455	33.766
-10% Speed	48.585	0.0165	46.87	1.007	0.684	0.448	0.484	0.751	0.750	1428	29.392	30.464
+10% Speed	40.250	0.0173	38.54	0.982	0.649	0.494	0.736	0.829	0.770	1428	35.478	37.051
Low Tide	44.391	0.0173	42.68	0.976	0.646	0.497	0.735	0.835	0.774	1428	32.169	33.457
High Tide	43.610	0.0173	41.90	0.976	0.646	0.497	0.735	0.836	0.773	1428	32.745	34.080
53% FEU Case	33.278	0.0147	32.01	0.554	0.009	0.277	0.009	0.435	0.009	1046	31.433	32.675

In order to have a clearer understanding, a relative comparison is studied on Table 5, in which each instance studied is contrasted with the main model. For instance, lowering crane hoist and spreader speeds by 10% causes a larger than 10% of operational time, however, increasing speeds by 10% has a relatively smaller effect on operational time, lowering it by only 8.5%. The changes in delays with reference to the main case can also be seen in the table. Distribution of the results gained from all iterations are oprovided on Appendix VI – Case 1 Results Study on Physical Changes.

Table 5. Case 1 Relative Comparison

Relative Comparison (%)		Total Opr. Time (%)	Net Opr. Time(%)	Waiting Time for Truck and Container (%)	Delays for Other Reasons (%)	Delays due to Crane or Spreader Defect (%)	Gross Crane Prod. (%)	Net Crane Prod.(%)
Ref. Case	**-10% Speed**	10.42%	10.84%	4.34%	-9.97%	-3.13%	-9.44%	-9.78%
Ref. Case	**+10% Speed**	-8.52%	-8.87%	1.70%	-0.82%	6.89%	9.32%	9.73%
Ref. Case	**Low Tide**	0.89%	0.92%	1.12%	-0.29%	7.76%	-0.88%	-0.92%
Ref. Case	**High Tide**	-0.89%	-0.92%	1.16%	-0.01%	7.79%	1.79%	0.93%
Ref. Case	**53% FEU**	-24.37%	-24.30%	-42.63%	-44.45%	-43.89%	-3.15%	-3.23%

As it can be easily discerned from Table 5, the tide alteration does not have a larger influence on either efficiency of the crane or the operational time. Examining the last row, which provides a comparison between main cases and the 53% FEU translation, 24.37% less operational time was required, which is a fair rate considering the 25.7% decrease in total crane moves in between two cases. (TEU case total crane moves are calculated as 1428 and for 53% FEU case - 1061).

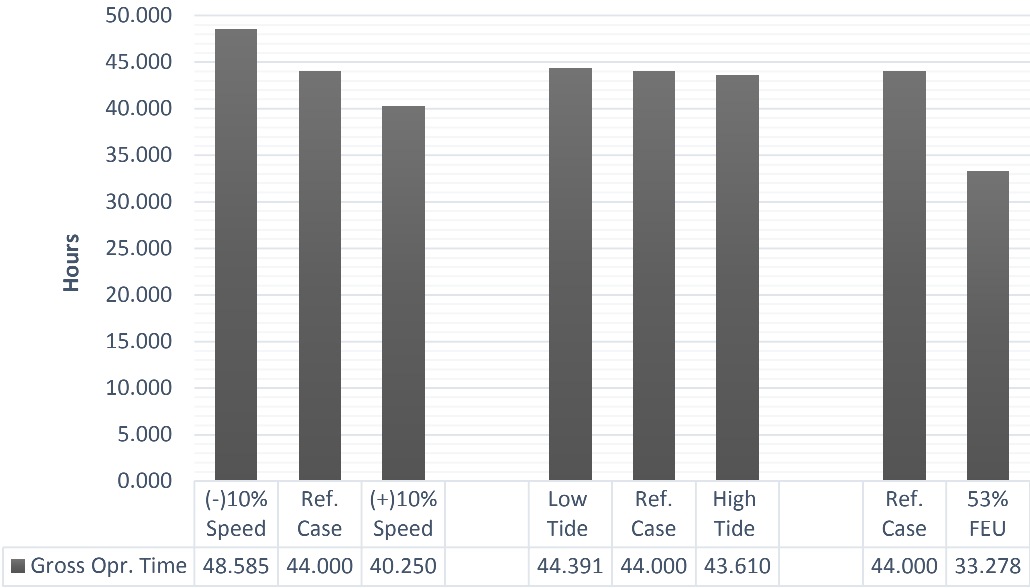


Figure 28. Bar Chart of Total Operational Time Comparison for Different Cases, represented in hours.

In Figure 28, the results of total operational times for different cases are represented visually. A dramatic alteration in time can be observed, when the speeds were changed. Increasing speeds provides an additional 9.32% in crane movements per gross hour, while decreasing speeds reduces gross crane productivity by a rate of 9.44%. Minor effects of high tide & low tide cases were observed, wherein gross crane productivity increased by 1.79% with high tide and decreased by 0.88% with low tide. Furthermore, FEU implementation created a significant variance in the dataset, decreasing the total operational time by 24.37%.

Case 2: Examining Multiple Number of Crane Usage on Port Efficiency

Decision on the crane number to be used in an operation is an important main step, which depends on the infrastructure and equipment of the terminal, the number of containers to be moved, the size of the ship, the availability of resources (berth, crane, trucks, operators, etc.) the timing of the current operation and the planned date of a future operation. Case 2 is provided to examine the effect of the crane number used in the operation on total operating time to determine the most suitable solution for such a problem.The numerical results are given in Table 6:

Table 6. Case 2 Multiple Number of Crane Usage Results Table, where μ represents mean, σ represents standard deviation.

Multiple Crane Case	Total Opr. Time (h)		Net Opr. Time (h)	Waiting Time for Truck and Container (h)		Delays for Other Reasons (h)		Delays due to Crane or Spreader Defect (h)		Total Mov.	Gross Crane Prod. (Mov/h)	Net Crane Prod. (Mov/h)
	μ	σ		μ	σ	μ	σ	μ	σ			
1 Crane	44.000	0.0170	42.291	0.965	0.619	0.498	0.624	0.775	0.808	1428	32.46	33.76
2 Crane	22.841	0.0123	21.965	0.384	0.007	0.191	0.007	0.301	0.008	731	32.00	33.28
3 Crane	16.628	0.0106	15.990	0.219	0.006	0.140	0.006	0.219	0.007	533	32.06	33.33
4 Crane	12.229	0.0090	11.767	0.202	0.005	0.101	0.005	0.159	0.006	389	31.81	33.05
5 Crane	9.711	0.0079	9.344	0.161	0.005	0.081	0.005	0.126	0.005	310	31.92	33.17

It is remarked that crane productivities were not changing considerably due to the fact that the operational times and total moves were changing likewise. Moreover, it can be distinguished that waiting times decreased consistently after each additional crane was enroled into the simulation. This can be seen as a natural result - since the total operational time was decreasing, the occurrence of delays in time were being reduced. However, in reality the situation can be more complex. Using more cranes means using more resources of the container terminal, which could in turn increase the probability of delay and defect occurrence. It can be easily presumed that terminal interface performance for five crane operations rather than one crane operations can have a very distinct effect on the outcome of the operation. Organisation of container/truck supply for these cases would be completely different - the congestion of the quay side, yard and storage area would be more hectic than in a one crane operation. It is worth noting that Discrete-Event Simulation is also a very powerful tool to solve such situations (See chapter 6.1). Distribution of results gained from all iterations are provided on Appendix VII – Case 2 Results Multiple Number of Crane Usage on Port Efficiency.

Table 7. Case 2 Table of Relative Comparison

Relative Comparison (%)		**Total Opr. Time (%)**	**Net Operational Time (%)**	**Waiting Time for Truck and Container (%)**	**Delays for Other Reasons (%)**	**Delays due to Crane or Spreader Defect (%)**	**Gross Crane Prod. (%)**	**Net Crane Prod. (%)**
Ref. Case	**2 Cranes**	-48.09%	-48.06%	-60.25%	-61.56%	-61.15%	-1.39%	-1.44%
Ref. Case	**3 Cranes**	-62.21%	-62.19%	-77.27%	-71.96%	-71.71%	-1.23%	-1.28%
Ref. Case	**4 Cranes**	-72.21%	-72.18%	-79.03%	-79.75%	-79.49%	-1.99%	-2.10%
Ref. Case	**5 Cranes**	-77.93%	-77.91%	-83.28%	-20.19%	-83.69%	0.35%	-1.74%

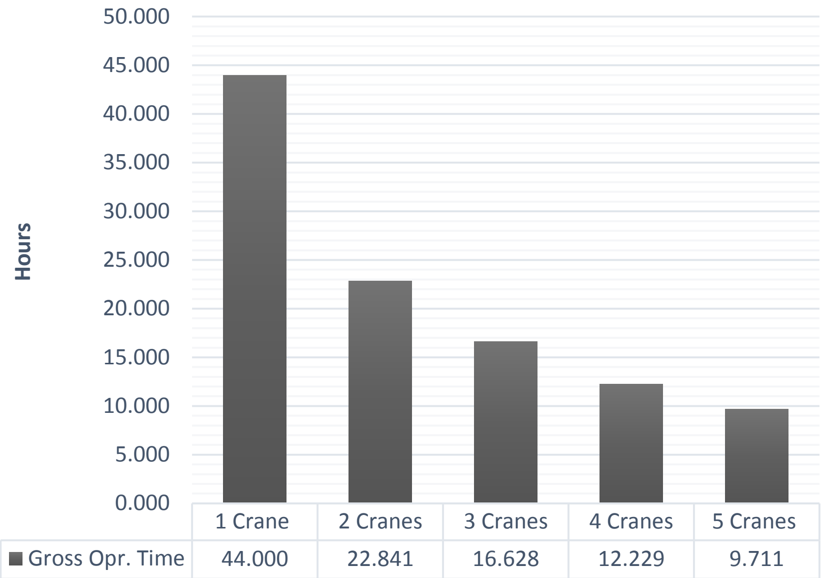


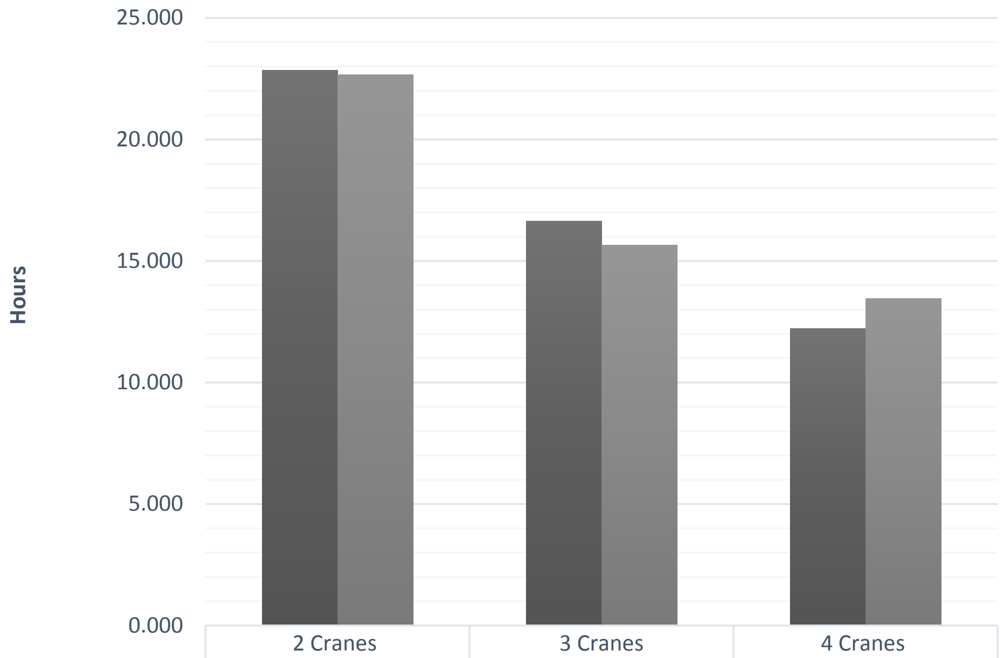
Figure 29. Bar Chart of Total Operational Time for different number of cranes, represented in hours.

Figure 29 clearly demonstrates that when the number of cranes increases, the total operational time decreases in an exponential manner. This is an evident aid for a container terminal in deciding how many cranes to use for a specific operation case.

For this instance, it can be observed that a difference of only 2,5 hours exists between a 4 crane and a 5 crane operation. This variation is relatively trivial compared to other time differences. It can be concluded that for a ship and operation case of this kind, the crane can be redundant.

DES Approach & Harries Approach Results Comparison

Figure 30 visualises the comparison of the results obtained by different approaches for the same cases. As expected, for 2 and 3 Crane simulations, total operational time attained was longer than in Harries approach. However, in a 4 Crane simulation, it was observed that DES result was shorter by approximately 1 hour and 10 minutes.



	2 Cranes	3 Cranes	4 Cranes
DES Approach	22.841	16.628	12.229
Harries Approach	22.66	15.66	13.45

Figure 30. Comparison of DES Approach & Harries Approach, represented in hours.

This difference can be caused by various reasons. First, the different approaches on hatch cover handling process can create a significant variance. In Harries approach, hatch cover handling for all bay is regarded as 900 seconds. Considering the reference case of this thesis, the average cycle time of a crane for one movement can be calculated as 111 seconds per move (44 hours/1428 moves). By adding the ABRATEC definition, counting hatch cover handling process as 1.5 moves, unloading all three hatches at one bay takes 500 seconds. This difference of 400 seconds occurs on each handling activity, i.e. loading and unloading. It is seen that in this simulation, the crane which defines the operational time handles two neighbour bays where hatch covers are defined. Only this circumstance can create a 1600 second, which is nearly 27 minutes, of difference between the two approaches.

Secondly, the crane allocation made in the DES approach can be more efficient than in Harries approach, which directly affects the total duration of the operational time. During the crane allocation process in this study, several different possibilities of allocation were observed from GUI, the results were examined and the most feasible allocation was taken into consideration. One another reason of this time variance can be the different spreader speeds in the hold. In this study, the maximum speed of a spreader is assigned as 1 m/s on deck or in hold; however, in Harries approach it is assigned 1m/s on deck and 0.7m/s in hold. Additionally, in this study the crane spreader movements were upgraded as curvy movements on quay side (See Figure 22). This movement shortens the spreader travel and obtains a time advantage on each move of a crane. Trailer height described in the simulation can be one other argument for the shortened time span of the simulation.

Case 3: Examining Multiple Number of Crane Usage on Port Efficiency of FEU Implemented Stowage Plan

The last case studied for this thesis is dedicated to the multiple crane effect on the 53% FEU implemented stowage condition. Because of this transformation, this study presents results closer to the reality, which can be used to define the total berthing time of the ship. Cranes were allocated for the same number of bays, as it was performed on case 2. However, it can be seen that the total moves performed by cranes are different than case 2, as a result of conversion. The numerical results are given at Table 8.

Table 8. Examining Multiple Number of Crane Usage on Port Efficiency of FEU Implemented Stowage Plan, where µ represents mean, σ represents standard deviation.

53% FEU Multiple Crane Comparison	Total Opr. Time (h)		Net Opr. Time (h)	Waiting Time for Truck and Container (h)		Delays for Other Reasons (h)		Delays due to Crane or Spreader Defect (h)		Total Mov.	Gross Crane Prod. (Move/h)	Net Crane Prod. (Move/h)
	µ	σ		µ	σ	µ	σ	µ	σ			
1 Crane	33.278	0.0147	32.013	0.554	0.009	0.277	0.009	0.435	0.009	1061	31.921	33.178
2 Crane	16.673	0.0104	16.037	0.279	0.006	0.139	0.006	0.219	0.007	531	31.849	33.111
3 Crane	12.864	0.0093	12.374	0.215	0.005	0.107	0.005	0.169	0.006	412	32.027	33.296
4 Crane	9.488	0.0080	9.132	0.157	0.004	0.078	0.004	0.123	0.005	302	31.829	33.072
5 Crane	7.240	0.0068	6.967	0.120	0.004	0.060	0.004	0.094	0.004	232	32.044	33.301

It was seen that FEU implementation does not affect the crane productivities severely. However, a significant decrease was seen on delays. This can be explained by the total number of crane movements. The less the movements are, the less the delays applied on the crane.
Table 9 states the relative comparison of one crane and multiple cranes. It was observed that the relative changes on total operational time is very similar to Case 2.
Distribution of result gained from all iterations are given on Appendix IIX – Case 3 - Examining Multiple Number of Crane Usage on Port Efficiency of FEU Implemented Stowage Plan Results.

Table 9. Examining Multiple Number of Crane Usage on Port Efficiency of FEU Implemented Stowage Plan Relative Comparison Table

Relative Comparison (%)		**Total Opr. Time (%)**	**Net Opr. Time (%)**	**Waiting Time for Truck and Container (%)**	**Delays for Other Reasons (%)**	**Delays due to Crane or Spreader Defect (%)**	**Gross Crane Prod. (%)**	**Net Crane Prod. (%)**
Ref. Case	**2 Cranes**	-49.90%	-49.90%	-49.70%	-49.70%	-49.77%	-0.23%	-0.20%
Ref. Case	**3 Cranes**	-61.34%	-61.35%	-61.19%	-61.20%	-61.22%	0.33%	0.36%
Ref. Case	**4 Cranes**	-71.49%	-71.48%	-71.73%	-71.82%	-71.76%	-0.29%	-0.32%
Ref. Case	**5 Cranes**	-78.24%	-78.24%	-78.33%	-78.34%	-78.41%	0.38%	0.37%

Figure 31 presents the total operational time bar chart comparison for multiple crane simulation. Similar to case 2, an exponential-like decrease was observed, where one crane operation took 33 hours 17 minutes, 2 cranes operation took 16 hours 40 minutes, 3 cranes operation took 12 hours 52 minutes, 4 cranes operation took 9 hours 29 minutes and 5 cranes operation took 7 hours 14 minutes.

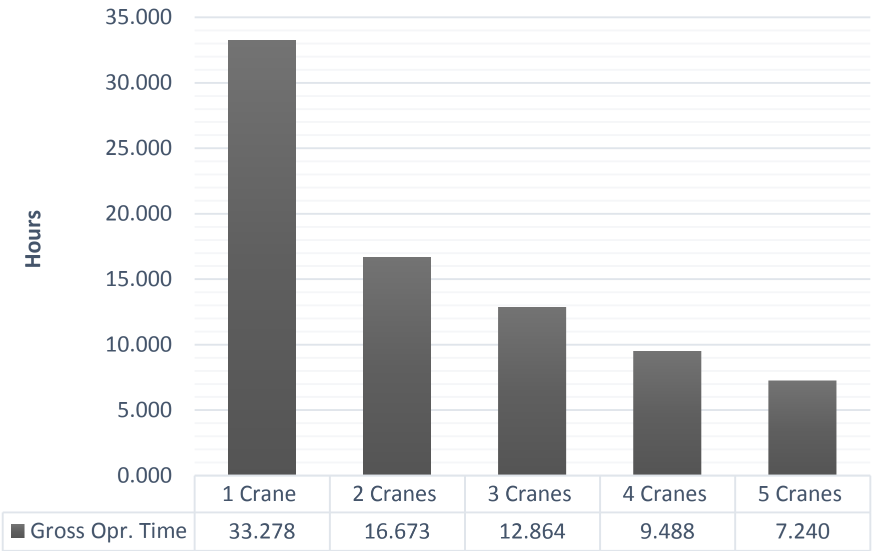


Figure 31. Case 3 Bar Chart Comparison

These values were the closest outcomes to the reality, for the observed bay plan and stowing case.

6. CONCLUSIONS AND DISCUSSIONS

The thesis examines the port efficiency of a new bay plan design by using a stochastic approach. A fully parametric Discrete-Event Simulation model was created, wherein various specifications regarding a container terminal were implemented. A real container terminal was statistically analysed, different reasons causing operational delays were discussed and finally implemented into the simulation. Simulation calibration process was performed in comparison to a real operational report, where, similarly to the examined stowing plan, mainly unloading operations were performed. In the simulation as well as in the operational report, same net operational times were obtained and then delays were incorporated into the simulation to compare gross operational times. Results with 8 minutes of approximation were obtained and simulation model was calibrated.

Different simulation cases were studied to observe the effect of physical differences and different number of crane usage. It was observed that a 10% speed increase of crane elements reduced the operation time by a rate of 8.52%, yet, a 10% decrease in speed of crane elements increased the operation time by a rate of 10.42%. Besides that, high tide or low tide did not affect port time significantly. In high tide, where the ship is escalated by 0.5m, 1.79% rise on gross crane productivity was calculated; while in low tide this rate was computed as a decline of 0.88%.

Moreover operations of up to five cranes were simulated to examine the effects on berthing time of the ship. Total operational time of the ship was determined by the crane which completed operational execution the latest. As in the reference case, the total operational time to perform 1428 crane moves with a single crane was calculated to be 44 hours, while 2, 3, 4 and 5 crane operations took 22 hours 51 minutes, 16 hours 38 minutes, 12 hours 14 minutes and 9 hours 43 minutes respectively.

Additionally, in order to obtain data to obtain real berthing time, 53% of all containers were converted to FEUs and the case was studied with up to five crane operations. For a single crane simulation, a 24.37% decline was observed in total operational time. For multiple crane simulations, the rates obtained were similar to all TEU multiple crane analyses.

Lastly, it is seen that DES can play a significant role on port operations management. Many “what-if” scenarios can be carried out during operation planning and precise answers can be obtained regarding to operational strategies i.e. how many crane is needed to perform the most feasible operation.

To sum it up, it is clarified that DES is a very reliable tool to inspect the port efficiency of a new bay plan design precisely. With the light of all the findings presented in this thesis, this research project is realized to contribute to the operational efficiency evaluation of new bay plan designs for container ships, as well as productivity assessment and port management on maritime container terminals.

6.1. Suggestion for Future Researchers

The simulation model designed for this thesis focused on the quay side operations for a container terminal to analyse performance of a new bay plan design. Even though many features were developed regarding to this study, it is not an end but a start for a new horizon of container ship optimization. It has been always thought that the hydrodynamic, structural, propulsion etc. performance of a container ship is the key points of efficiency. However, optimization should be considered as a global concept, where operational efficiency is as important as the others. Regarding to this approach, an optimization engine could be coupled with DES software and other software's where the other aspects can be examined to reach aim of global optimization.

One of the first improvement can be developed at the simulation model is to model re-handling operation. This operation is explained in chapter 3.2. This feature could not be added due to the limited time of the research.

Moreover, to obtain more realistic semi-random variables i.e. delays distributions, truck and container arrival of the terminal can be modelled. For example, increasing the crane speeds can expand the waiting time for truck and container, since it is more probable to observe this delays by decreasing cycle time of crane. To be able to obtain the real delay times, the entire interface of a port can be created to calculate real waiting times. Quest Software is a tool where an intermodal container terminal can be created and simulated with all the aspects.

One other issue can be examined in the near future is the double cycling approach. Container crane can unload a container and return to the port with an export container, which decreases empty crane travel and increase cycle elapsed time [25]. DES is the perfect approach to solve this complexity.

In addition, the research can be extended to a more global case. Such as, during the preliminary design process the route and the ports are known, these container terminals can be examined and the performance of the ship can be predicted during her life cycle.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[1] Drewry Maritime Research, (2014), Container Market Annual Review and Forecast 2014.

[2] Brett, D. (2014) *Asian Container Ports struggle with the worst congestion in 20 years* [online] http://www.lloydsloadinglist.com/freight-directory/sea/Asian-container-ports-struggle-with-the-worst-congestion-in-20-years/1739.htm#.VKZhyiuG-qn [Accessed 03.12.2014].

[3] Wiesmann, A., 2010. Slow steaming – A viable long-term option? Wartsila Technical Journal, (2) 49-55.

[4] Rodrigue, J.P., (2013) *The Geography of Transport Systems*. [Online] Available from http://www.people.hofstra.edu/geotrans/eng/ch8en/conc8en/fuel_consumption_containerships.html [Accessed 20.10.2014].

[5] Harries, S., Dolerud, E., Sames, P. C. (2013), Port Efficiency Simulations for the Design of Container Ships. Computer and IT Applications in the Maritime Industries-COMPIT, 348-362.

[6] Nehrling, B.C. (1970) Container Ship Loading and Unloading Simulation.

[7] Liu, Q. (2010), Efficiency Analysis of Container Ports and Terminals. Thesis (PhD). University College London.

[8] Goussiatiner, A., 2009. Efficiency of Multi-Trailer Systems for Ship to Stacks Container Transportation. Port technology International, (43), 78-82.

[9] Gadeyne, B., Verhamme. P., 2011. Optimizing Maritime Container Terminal Operations. Thesis (M.Sc.) Ghent University.

[10] Won,S. H., Kim, K. H., 2009. An Integrated Framework for Various Opeation Plans In Container Terminals. Polish Maritime Research Journal, Vol. 16, 51-61.

[11] Fan, L.; Low M. Y. H.;Ying, H. S.; Jing, H.W.; Min, Z.; Aye, W.C., 2010. Stowage Planning of Large Containership with Tradeoff between Crane Workload Balance and Ship

Stability. Proceedings of International MultiConference of Engineers and Computer Scientists Vol III.

[12] Rizzoli A.E., Gambardella L.M., Zaffalon M., Mastrolilli M., 1999. Simulation for the evaluation of optimised operations policies in a Container Terminal, Maritime & Industrial Logistics Modelling and Simulation.

[13] Carteni, A., 2009. Simulation of a Container Terminal Through a Discrete Event Approach: Literature Review and Guidelines for Application. *Association for European Transport.*

[14] Ambrosino, D., Tànfani, E., 2012. An Integrated Simulation and Optimization Approach for Seaside Terminal Operations. *European Conference on Modelling and Simulation.*

[15] Maersk Lines Press Releases, 2010. *Slow Steaming Here to Stay* [Online]. Maersk Lines. Available from: http://www.maersk.com/en/the-maersk-group/press-room/press-release-archive/2010/9/slow-steaming-here-to-stay [Accessed 23.08.2014].

[16] Robinson, S., 2004. *Simulation: The Practice of Model Development and Use.* West Sussex, England: Wiley.

[17] Fishman, G. S., 2001. *Discrete-Event Simulation: Modelling, Programing and Analysis*. Newyork, US: Springer Verlag Newyork Inc.

[18] Goussiatiner, A., 2009. *Systematic Approach to Quayside Container Crane Productivity Improvement* [Online] Sandwell Engineering Inc. https://tr.scribd.com/doc/11044764/Crane-Productivity-Improvement [Accessed 12.09.2014].

[19] *Libra Container Terminal.* [Online] Available from http://latinports.org/wp-content/uploads/2014/07/libraTerminalRio-720x340.jpg [Accessed 20 November 2014].

[20] Libra Container Terminal. [Online] Available from http://www.revistafatorbrasil.com.br/imagens/fotos2/terminal_libra_rio_14 [Accessed 20 November 2014].

[21] *Libra Container Terminal. [Online]* Adapted from http://www.grupolibra.com.br/inc/img/en_terminais/en_dados-operacionais-rio.png [Reached 20 November 2014].

[22] Anderson, T. W.; Darling, D 1952. Asymptotic Theory of Certain "Goodness of Fit" Criteria Based on Stochastic Processes. *TheAnnals of Mathematical Statististics* 23 (2), 2, 193-212.

[23] Papanikolaou, A., Kalospyros, K., (1990), *Computer-aided planning and optimization of containership stowage*, 5th Int. Congress on Marine Technology, Athens.

[24] Goussiatiner, A. (2009) *Crane Productivity Improvement* [online] Sandwell Engineering Inc. Available from https://tr.scribd.com/doc/11044764/Crane-Productivity-Improvement [Accessed 12.09.2014].

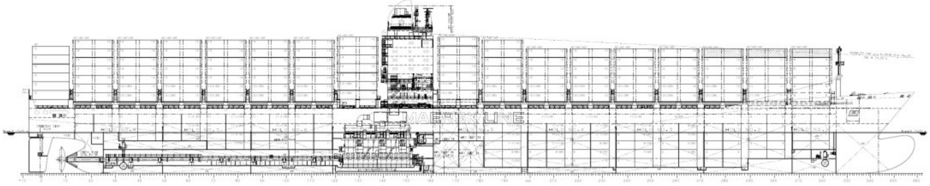
[25] Goussiatiner, A. (2008) *In Pursuit of Productivity* [online] Sandwell Engineering Inc. Available from https://tr.scribd.com/doc/2170927/Terminal-Productivity-Container-Management [Accessed 12.09.2014].

APPENDIXES

Appendix I – Hatch cover design reference document

P+S WERFTEN

P+S WERFTEN GmbH
An der Werft 5
18439 Stralsund
GERMANY



MAIN PARTICULARS

Length over all	293.86 m
Length betw. perp.	278.20 m
Breadth, moulded	32.18 m
Depth, to Main Deck	21.40 m
Draught, design	12.20 m
Draught, summer	13.50 m
Corresp. Deadweight	53 868 tdw
Speed (Design Draught, 85% MCR)	approx. 29.20 kn
Gross Tonnage (GT)	48 853
Cruising range	approx. 11 500 sm
Complement	crew of 25 + 6 repair

CLASS: **L**loyd's **R**egister
✠100 A1 Container Ship *IWS, LI
Ship Right (SDA, FDA, CM)
✠ LMC, UMS
Descriptive Note: Shipright SCM, PART HIGHER TENSILE STEEL

TANK CAPACITIES

Heavy fuel oil	6 515 m³
Marine diesel oil	407 m³
Lubricating oil (Cyl.+storage)	516 m³
Fresh water	328 m³
Ballast water	26 763 m³

ENGINE PLANT

Main engine DOOSAN – Sulzer 12RT-flex-96C
MCR: 68 640 kW/102 rpm
Fixed-pitch propeller
Aux. diesel generators 4 x Cat/MaK 6M32C
each 2765 $kW_{el.}$/600 rpm
Emerg. diesel generator
1 x 260 $kW_{el.}$/1 800 rpm
Bow thruster 1500 kW
Stern thruster 1100 kW

EQUIPMENT

1 Monorail 11 t SWL, max. 4 m over board outr.
Fin stabilizing system 2 x 11.0 m^2
Seakeeping Decision Support System **SeaSense**

CONTAINER STOWAGE (SOLAS)

Capacity	40' x 9'6½''
On deck	1 409
Below deck	689
Total	2 098
corresponds to	4 196 equivalent TEU

Stack loads:

Size	Hold	Hatch Cover	On Deck		
	No.1-8	No.1-15	BAY 66	BAY39-37 above MR	BAY35-33
40'	227.5	120	120	120	102
20'	135	80	100	100	-

REEFER on Deck	(air cooled)	345 FEU
REEFER in Holds	(water cooled)	355 FEU
REEFER total		700 FEU

Hatches: Pontoon steel hatch covers
Hatch 1 + 9 : 13.34 x 13.63 m
Hatch 2: 2 x 13.34 x 8.03 + 13.34 x 7.48 m
Hatch 3-8, 10-15: 2 x 13.34 x 10.61 + 13.34 x 7.48 m

Stability (14t/TEU & 28t/FEU, homog., acc. to IMO)
▫ 9'6½"-Cont., 50% VCG 2 603 equival.TEU

PANMAX CONTAINER VESSEL

[Reached 01.09.2014]

Available from http://img.nauticexpo.com/pdf/repository_ne/32056/7270-dwt-19681_1b.jpg

Appendix II – ABRATEC Crane Productivity Calculations

ABRATEC

Filiado à AAPA – American Association of Port Authorities

- TTB – Tempo total decorrido entre a chegada do navio na barra ou fundeadouro, e o início de sua navegação desde o ponto até o cais do Terminal.
- TTBc – Considera o tempo decorrido na barra ou fundeadouro, por instrução do armador/agente, apesar de estar em berço disponível.
- TTBd – Tempo na barra por outros fatores alheios ao Terminal. Considera o tempo decorrido na barra ou fundeadouro, observado por razões tais como: fatores climáticos, fiscalização fito-sanitária, ou outras razões de força maior.
- TTBo – Tempo na barra por ocupação de berço. Tempo de permanência na barra resultante da efetiva ocupação dos berços dos Terminais, excluídos os tempo em 5.1 e 5.2, acima.
- TTPj – Tempo na barra por atraso ou perda de janela de atracação no Terminal por conta do Armador

3. Produtividade Bruta (PB) *(Movimentos/horas)*

Representa a performance operacional alcançada no atendimento de determinado navio em operação de cargas contêinerizadas, desconsiderando-se quaisquer paralisações operacionais ocorridas após estar o mesmo liberado e pronto para iniciar operações, independentemente de sua causa ou responsabilidade.
Definida como o resultado da divisão da movimentação total realizada a escala (inclusive tampões e remoções a bordo e via terra), pelo número total de horas em que o navio permaneceu atracado no Terminal e disponível para operações de carga/descarga de contêineres.

$$PB = \frac{TMCtrs + TMEhc + TMEog}{TOD}$$

Aonde:

- TMCtrs = Total de movimentos de contêineres
- TMEhc = Total de movimentos equivalentes de tampões
- TMEog = Total de movimentos equivalentes de contêineres fora do padrão (OOG)
- TOD = Tempo operacional disponível

6

ABRATEC

Filiado à AAPA – American Association of Port Authorities

Notas:

- Remoções à bordo devem ser computadas como um movimento
- Remoções via terra, contados cada movimento (descarga e embarque)
- Incluir os movimentos realizados com as caixas de castanhas (bins) de/para bordo.

3.1. Conversão do número de movimentos de tampas operadas em movimentos equivalentes para obtenção de TMEhc *(movimentos).*

Multiplica-se o número de movimentos de tampões (hatch-covers) pelo índice de conversão adotado (IHC de 1,5). Desta forma:

$$TMEhc = NMT \times IHC$$

Aonde:

- NTM = Número de movimentos de tampões, aonde retirada e colocação = 2 movimentos, resultando em TMEhc = 3.
- IHC = Índice de conversão de movimentação de tampões em movimentos equivalentes de contêineres (adotado = 1,5)

3.2. Conversão do número de contêineres fora de padrão ou com cargas com excesso (OOG) em movimentos equivalentes para obtenção de TMEog (*movimentos*).

Multiplica-se o número de movimentos de contêineres fora de padrão e/ou com cargas com excesso (OOG) pelo índice de conversão adotado (IOG de 4,0). Desta forma:

$$TMEog = NMO \times IOG$$

Aonde:

- NMO = Número de movimentos de contêineres fora de padrão e/ou com cargas com excesso.
- LOG = Índice de conversão de movimentação de contêineres com carga em excesso ou fora de padrões ISO (OOG) em movimentos equivalentes de contêineres (adotado = 4,0).

3.3. Apropriação do tempo operacional disponível (TOD) *(horas)*

Como definido anteriormente, é o número total de horas corridas em que o navio permanece atracado no Terminal, iniciando-se a partir do momento em que é possível o desenvolvimento normal e ininterrupto de operações de carga/descarga de contêineres, até o encerramento das operações de carga/descarga e o seu respectivo *lashing*. Obtido como abaixo:

$$TOD = (HTL - HLN) - THCG$$

Aonde:

- HTL = Horário de término do *lashing* ao final das operações (hhmm).
- HLN = Horário de liberação do navio para inicio das operações (hhmm)
- THCG = Total de horas em que o navio operou <u>exclusivamente</u> cargas não contêinerizadas (horas)

<u>4. Produtividade Líquida (PL)</u> *(movimentos/horas)*

Representa a performance operacional alcançada no atendimento de determinado navio, na sua operação de cargas contêinerizadas exclusivamente. Obtida descontando-se, para seu cálculo, os tempos das paralisações ocorridas após estar o navio liberado para iniciar operações – desde que as causas ou responsabilidades destas paralisações não possam ser atribuídas ao Terminal propriamente dito.

Definida como o resultado da divisão da movimentação total realizada durante a escala (inclusive tampões, remoções a bordo e via terra, e contêineres fora de padrão ou com cargas com excesso – OOG), pelo número total de horas em que o navio permaneceu operacional – ou passível de ser operado – não o sendo por motivo de exclusiva responsabilidade do Terminal.

$$PL = \frac{TMCtrs + TMEhc + TMEog}{TOE}$$

Aonde:

- TCMtrs = Total de movimentos de contêineres
- TMEhc – Total de movimentos equivalentes de tampões (ver acima)

Appendix III – The Summary of Report for the Operation to Calibrate the Simulation

Libra Terminais

CARGO OPERATION REPORT

Date: 13/09/2014
Hour: 21:16
Page: 1

VESSEL: 33471 - HYUNDAI PLATINUM
VOY Nr: 006W/006W
SHED Nr: BERTH L1

GANGWAY DOWN:	13/09/2014 08:00
OPERATION STARTED:	13/09/2014 11:20 OK
OPERATION COMPLETED:	13/09/2014 21:08 OK
NO WORK:	00:00
TOTAL WORKED HOURS:	09:48

LOADED:	126 OK
DISCHARGED:	624 OK
SHIFTINGS:	6 OK
H.COVERS:	18 OK
GRAN TOTAL MOVES:	774 OK
PORTAINER MOVES:	750
VESSEL'S CRANE MOVES:	0

VESSEL'S PRODUCTIVITY

VESSEL'S GROSS PRODUCTIVITY/HOUR:	79,0
GROSS GANG PRODUCTIVITY:	26,7
NET GANG PRODUCTIVITY:	32,0

REMARKS: 4 MOVES

GESTOR: ALCIDES POSSATO

Libra Terminais

STATEMENT

Date: 13/09/2014
Hour: 21:16

PORT OF. RIO DE JANEIRO VESSEL: HYUNDAI PLATINUM VG : 006W/006W Page: 1
BERTH: BERTH L1
Number of Gangs: 3 Working Time: from 07:00 H to 13:00 H Date: 13/09/2014

SERVICE		Gang Nbr. #1		Gang Nbr. #2		Gang Nbr. #3		Gang Nbr. #4		TOTAL	
Gear Used		[illegible]		P4		P8					
		FULL	MTY	FULL	MTY	FULL	MTY	FULL	MTY	FULL	MTY
LOADING	Total Loaded	-	-	-	21	-	-	-	-	-	21
DISCHARGING	Total Discharged	16	-	46	-	62	-	-	-	123	-
SHIFTING BOARD	Total Shifted	-	-	-	-	-	-	-	-	-	-
SHIFTING QUAY	Total Shifted	-	-	1	-	-	-	-	-	1	-
GRAN TOTAL		16	-	46	21	62	-	-	-	124	21

		Gang Nbr. #1	Gang Nbr. #2	Gang Nbr. #3	Gang Nbr. #4	TOTAL
HATCH COVER	Opening	-	-	-	-	-
	Closing	-	-	-	-	-
	Shifting	-	-	-	-	-
Total Covers moves		-	-	-	-	-
Total moves		16	67	62		145
Total Vessel's Crane moves		-	-	-	-	-
TOTAL HRS/GANG		01:40	01:40	01:40		05:00
TOTAL DELAY HRS		01:11				01:11
WORKING HRS NET		00:29	01:40	01:40		03:19

Gang Productivity:		1st gang:	2nd gang:	3rd gang:	4th gang:	Gang
29,0	Mvs/hr Gross	9,6 mvs/hr	40,2 mvs/hr	37,2 mvs/hr	0,0 mvs/hr	Gross
38,0	Mvs/hr Net	33,1 mvs/hr	40,2 mvs/hr	37,2 mvs/hr	0,0 mvs/hr	Net

REMARKS: 1ST GANG:
11:32 / 11:36 ADJUSTING TWISTLOCK (CONTAINER)
11:38 / 12:46 GANTRY CRANE DEFECT
2ST GANG:
3ST GANG:

By: SCBRUNO
Operator Terminal - 1
Name: ALCIDES POSSATO

Libra Terminais

STATEMENT

Date: 13/09/2014
Hour: 21:16

PORT OF: RIO DE JANEIRO VESSEL: HYUNDAI PLATINUM VG.: 006W/006W Page: 2
BERTH: BERTH L1
Number of Gangs: 3 Working Time: from 13:00 H to 19:00 H Date: 13/09/2014

SERVICE		Gang Nbr. #1		Gang Nbr. #2		Gang Nbr. #3		Gang Nbr. #4		TOTAL	
Gear Used		P3		P4		P5					
		FULL	MTY	FULL	MTY	FULL	MTY	FULL	MTY	FULL	MTY
LOADING	Total Loaded	19	20	-	56	-	-	-	-	19	76
DISCHARGING	Total Discharged	101	-	167	-	169	-	-	-	427	-
SHIFTING BOARD	Total Shifted	-	-	-	-	-	-	-	-	-	-
SHIFTING QUAY	Total Shifted	-	-	2	-	-	-	-	-	2	-
GRAN TOTAL		120	20	159	56	169	-	-	-	448	76
HATCH COVER	Opening	1		3		4		-		8	
	Closing	1		-		4		-		5	
	Shifting	-		-		-		-		-	
Total Covers moves		2		3		8		-		13	
Total moves		142		218		177		-		537	
Total Vessel's Crane moves		-		-		-		-		-	
TOTAL HRS/GANG		06:00		06:00		06:00				18:00	
TOTAL DELAY HRS		00:38		00:23		00:11				01:12	
WORKING HRS NET		05:22		05:37		05:49				16:48	

Gang Productivity:		1st gang:	2nd gang:	3rd gang:	4th gang:	Gang
29,8	Mvs/hr Gross	23,7 mvs/hr	36,3 mvs/hr	29,5 mvs/hr	0,0 mvs/hr	Gross
32,0	Mvs/hr Net	26,5 mvs/hr	38,8 mvs/hr	30,4 mvs/hr	0,0 mvs/hr	Net

REMARKS: 1ST GANG:

13:03 / 13:09 AWAITING TRUCK
14:01 / 14:02 AWAITING TRUCK
14:05 / 14:25 GANTRY CRANE DEFECT
14:36 / 14:38 AWAITING TRUCK
17:34 / 17:37 AWAITING CARGO
18:24 / 18:30 AWAITING CARGO

2ST GANG:

13:10 / 13:11 AWAITING TRUCK
17:01 / 17:11 AWAITING CARGO
17:42 / 17:51 AWAITING CARGO
18:31 / 18:34 AWAITING CARGO

3ST GANG:

15:21 / 15:32 GANTRY CRANE MANOEUVRE

By: SCBRUNO
Operator Terminal - 1
Name: ALCIDES POSSATO

Libra Terminais

STATEMENT

Date: 13/09/2014
Hour: 21:16

PORT OF: RIO DE JANEIRO VESSEL: HYUNDAI PLATINUM VG.: 006W/006W Pago: 3
BERTH: BERTH L1
Number of Gangs: 3 Working Time: from 19:00 H to 01:00 H Date: 13/09/2014

SERVICE		Gang Nbr. #1		Gang Nbr. #2		Gang Nbr. #3		Gang Nbr. #4		TOTAL	
Gear Used		P3		P4		P6					
		FULL	MTY	FULL	MTY	FULL	MTY	FULL	MTY	FULL	MTY
LOADING	Total Loaded	1	-	-	9	-	-	-	-	1	9
DISCHARGING	Total Discharged	4	-	6	-	64	-	-	-	74	-
SHIFTING BOARD	Total Shifted	-	-	-	-	-	-	-	-	-	-
SHIFTING QUAY	Total Shifted	1	-	2	-	-	-	-	-	3	-
GRAN TOTAL		6	-	8	9	64	-	-	-	78	9
HATCH COVER	Opening	-		-		1		-		1	
	Gloaing	-		3		1		-		4	
	Shifting	-		-		-		-		-	
Total Covers moves		-		3		2		-		5	
Total moves		6		20		66		-		92	
Total Vessel's Crane moves		-		-		-		-		-	
TOTAL HRS/GANG		02:08		01:31		00:21				04:00	
TOTAL DELAY HRS				00:06		00:18				00:24	
WORKING HRS NET		02:08		01:25		00:03				03:36	

Gang Productivity:		1st gang:	2nd gang:	3rd gang:	4th gang:	Gang
23,0	Mvs/hr Gross	2,8 mvs/hr	13,2 mvs/hr	188,6 mvs/hr	0,0 mvs/hr	Gross
25,6	Mvs/hr Net	2,8 mvs/hr	14,1 mvs/hr	1320,0 mvs/hr	0,0 mvs/hr	Net

REMARKS: 1ST GANG:
COMPLETED OPERATION AT 21:00
25T GANG:
20:16 / 20:22 GANTRIES BOOMS WERE TO HEAVED UP DUE TO MANOEUVRING SAFETY
COMPLETED OPERATION AT 20:31
3ST GANG:
18:05 / 18:06 AWAITING TRUCK
19:34 / 19:42 UNLASHING CARGO
20:17 / 20:24 GANTRIES BOOMS WERE TO HEAVED UP DUE TO MANOEUVRING SAFETY
20:43 / 20:45 AWAITING TRUCK
COMPLETED OPERATION AT 19:21

Operator Terminal 1
By: SGBRUNO Name: ALCIDES POSSATO

NAVIS SPARCS 3.7.30.6 *Libra Terminais Rio* Crane Work List - HYUNDAI PLATINUM - 33471

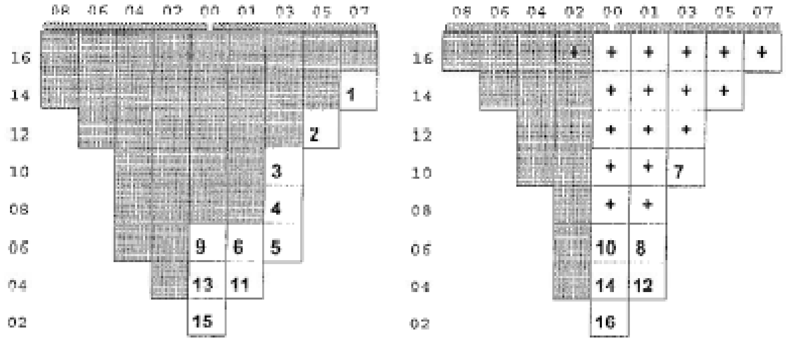
▶ P5	+SA0700	295 moves	25,0 mph	(planned)
▼ [illegible]	+SA0700	293 moves	25,0 mph	(planned)
34A Disch		9x40'		
35A Disch		16x20'	(2x6 twins)	
34A Load		21x40'		
31A Disch		6x20'	(2x3 twins)	
27A Disch		9x20'	(2x4 twins)	
26A Disch		70x40'		
26B Disch		47x40'	07 OH 68CM !	
27B Disch		48x20'	(2x22 twins)	
26B Load		64x40'		
25A Load		1x20'		
27A Load		1x20'		
26A Load		1x40'		
▶ 33	+SA0700	168 moves	23,0 mph	(planned)

12/9/2014 15:38:19 **Crane Work List - HYUNDAI PLATINUM - 33471** Page 1 of 1

NAVIS SPARCS 3.7.30.6 *Libra Terminais Rio* Sequence Plan: 33471 Rev # 1

Terminal 1 Rio SHIP DISCHARGE SHEET HYUNDAI PLATINUM

07 (06) Below 05 Below



Sequence 1 to 16

Seq	Terno	Container	Tipo	Peso	Status	Obs.	Loc.Pátio
1	P3	STBU2625569	2270	28,0	FCL	◇	070714
2	P3	STBU2621780	2270	28,0	FCL	◇	070512
3	P3	STBU2621291	2270	28,0	FCL	◇	070310
4	P3	UTCU4135782	2270	28,0	FCL	◇	070308
5	P3	SNTU6003514	2270	28,0	FCL	◇	070306
6	P3	CNSU2071933	2200	20,3	FCL		070106
7	P3	STBU2621096	2270	28,0	FCL	◇	050310
8	P3	KKTU7914124	2200	12,3	FCL		050106
9	P3	SUDU7395133	2200	18,4	FCL		070006
10	P3	NYKU3520509	2200	12,8	FCL		050006
11	P3	DRYU2208995	2200	20,3	FCL		070104
12	P3	GLDU2893259	2200	20,3	FCL		050104
13	P3	KKTU7543532	2200	15,5	FCL		070004
14	P3	KKTU7126539	2200	15,5	FCL		050004
15	P3	FCIU4831933	2200	20,3	FCL		070002
16	P3	HDMU2382136	2200	20,3	FCL		050002

12/9/2014 15:38:42 **Ship Discharge Sheet** Page 2 of 35

Appendix IV –Additional Characteristics of Analysed Terminal

- 99,600 sq.m. covered warehouse for import goods,
- 270 plugs for refrigerated containers,
- 4 RTGs,
- 13 Kalmar reach stackers.

At the bonded port:

- 23 thousand sq.m. total area.
- 3 thousand sq.m. covered warehouse for export.
- Computerized management system for the entire terminal.
- Static capacity of 2,500 TEU.
- Completely sealed vault with restricted access.
- Computerized operation control.
- Intermodal rail and highway connection.

Appendix V – Calibration Case Results

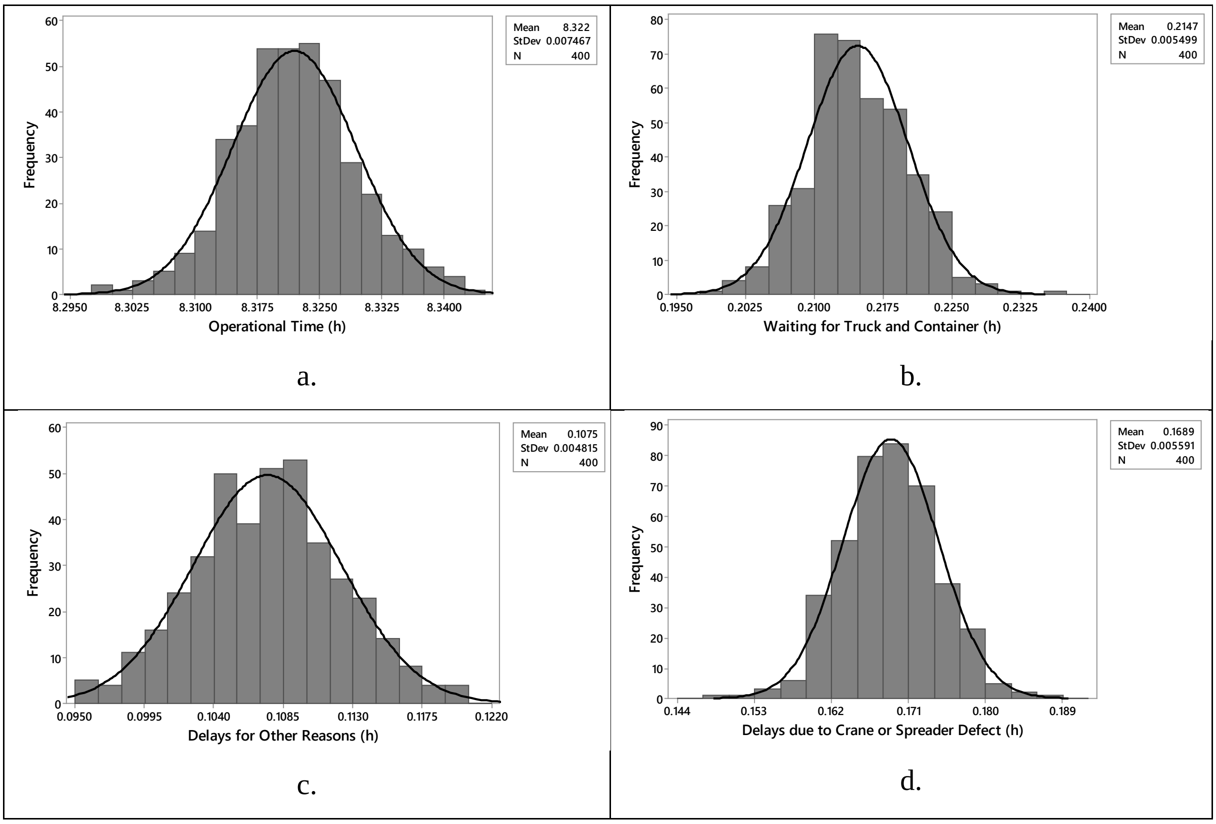


Figure 32. Crane 2 calibration results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

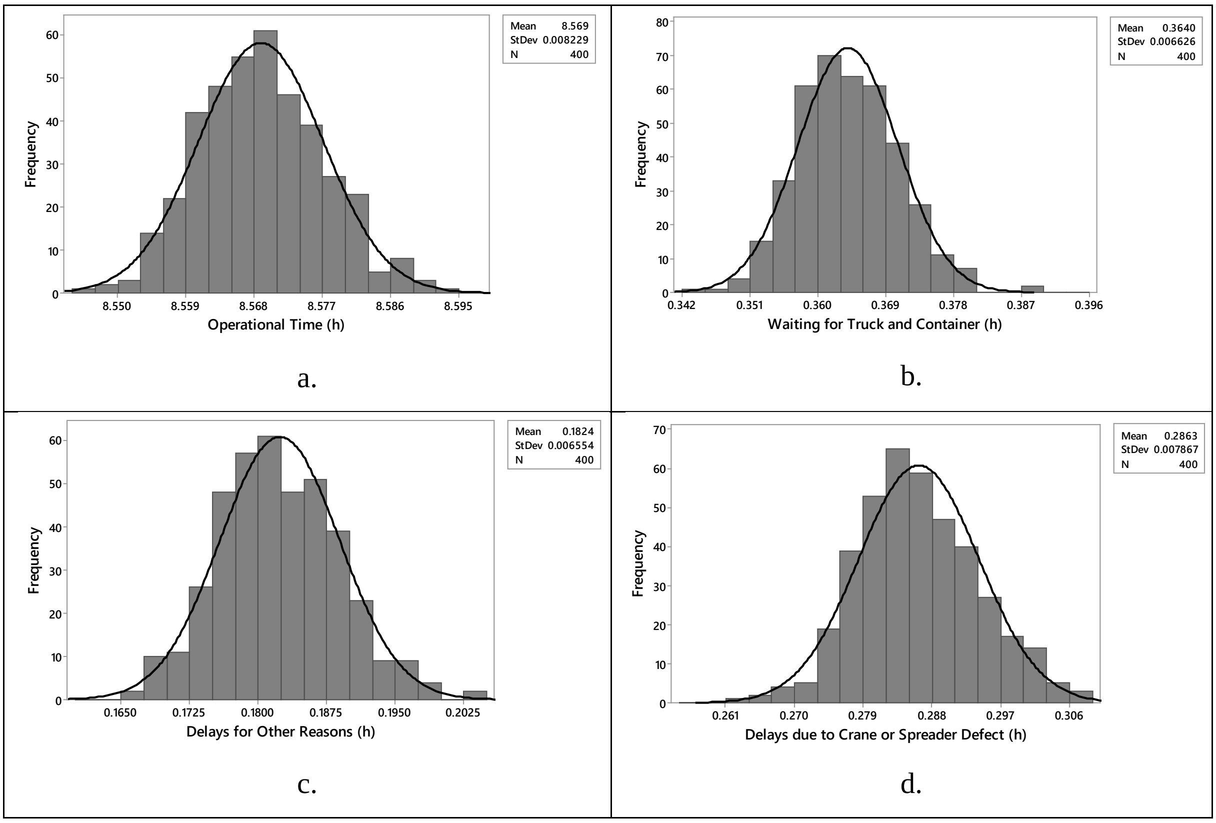


Figure 33. Crane 3 calibration results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

Appendix VI – Case 1 Results Study on Physical Changes

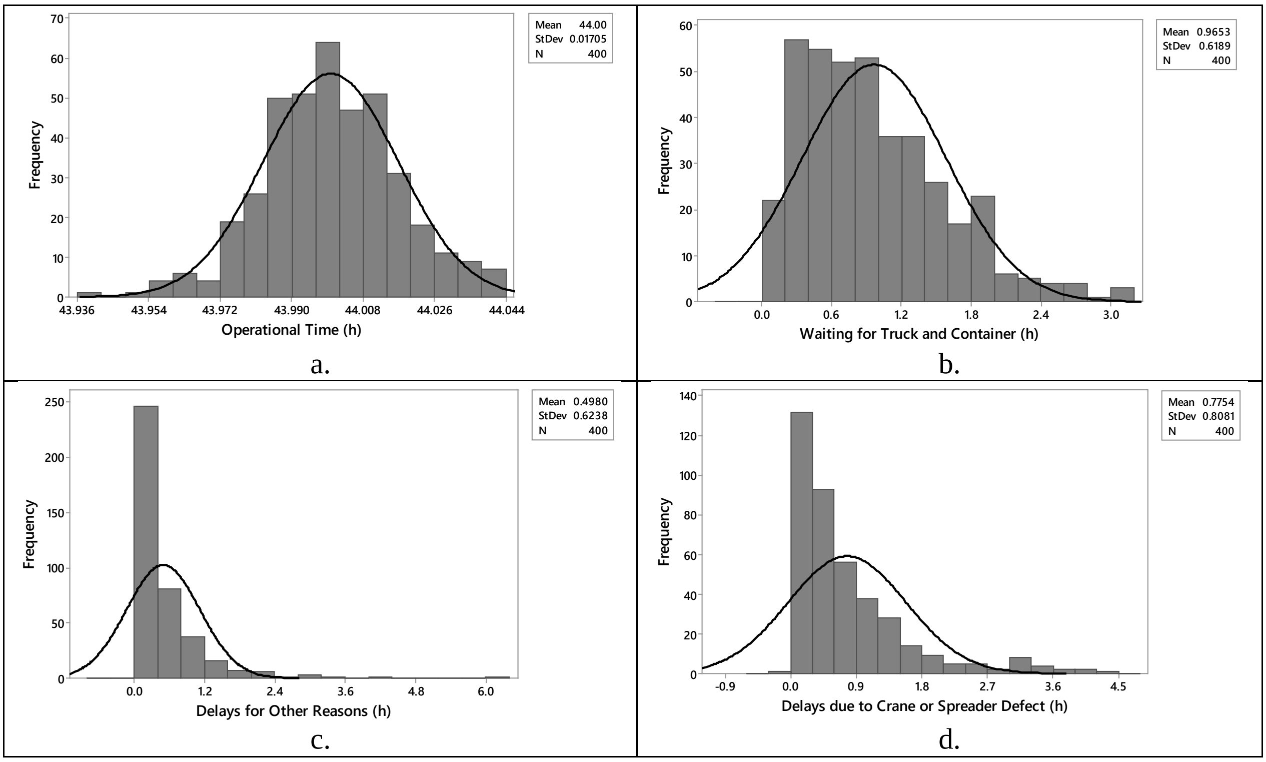


Figure 34. Reference case results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

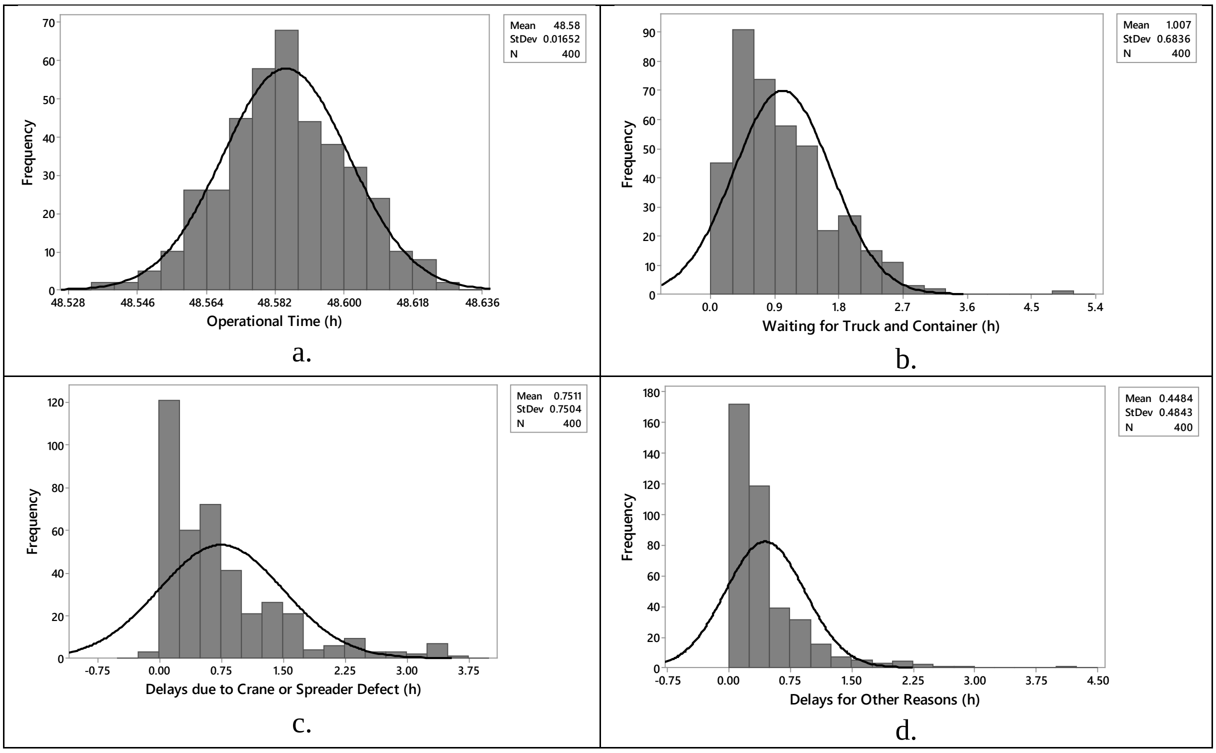


Figure 35. -10% Crane Speeds case results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

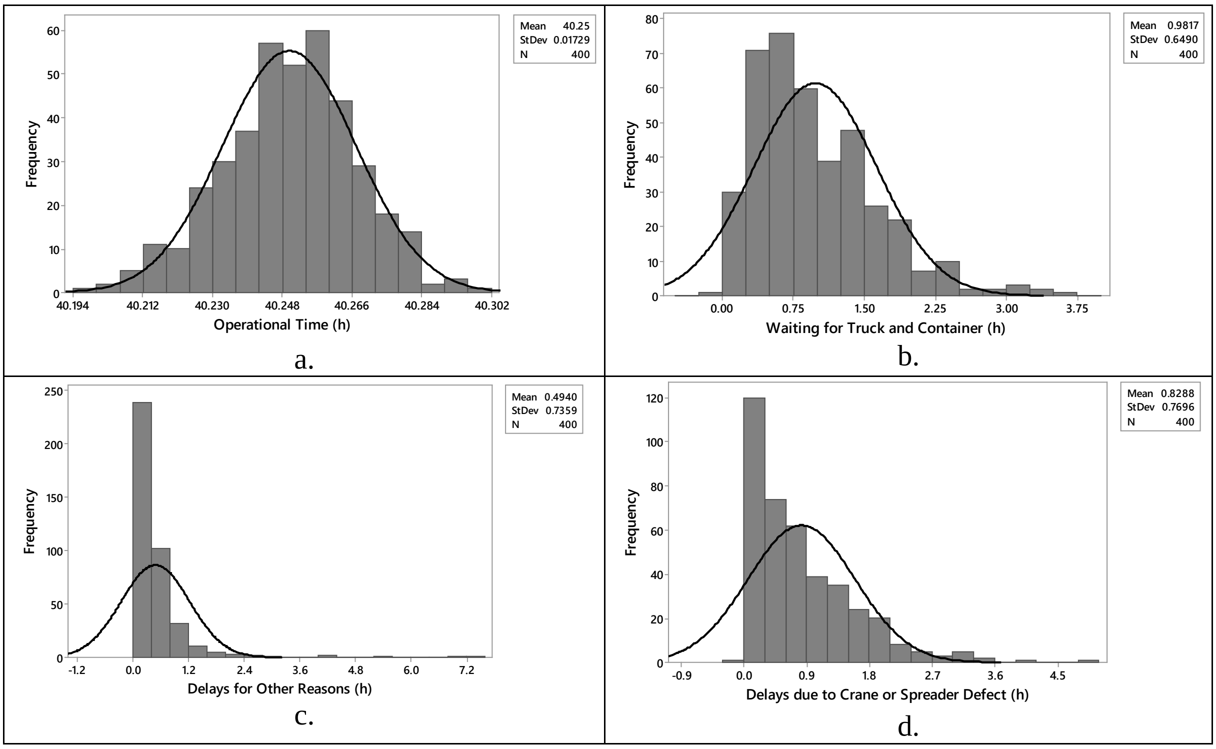


Figure 36. +10% Crane Speeds case results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

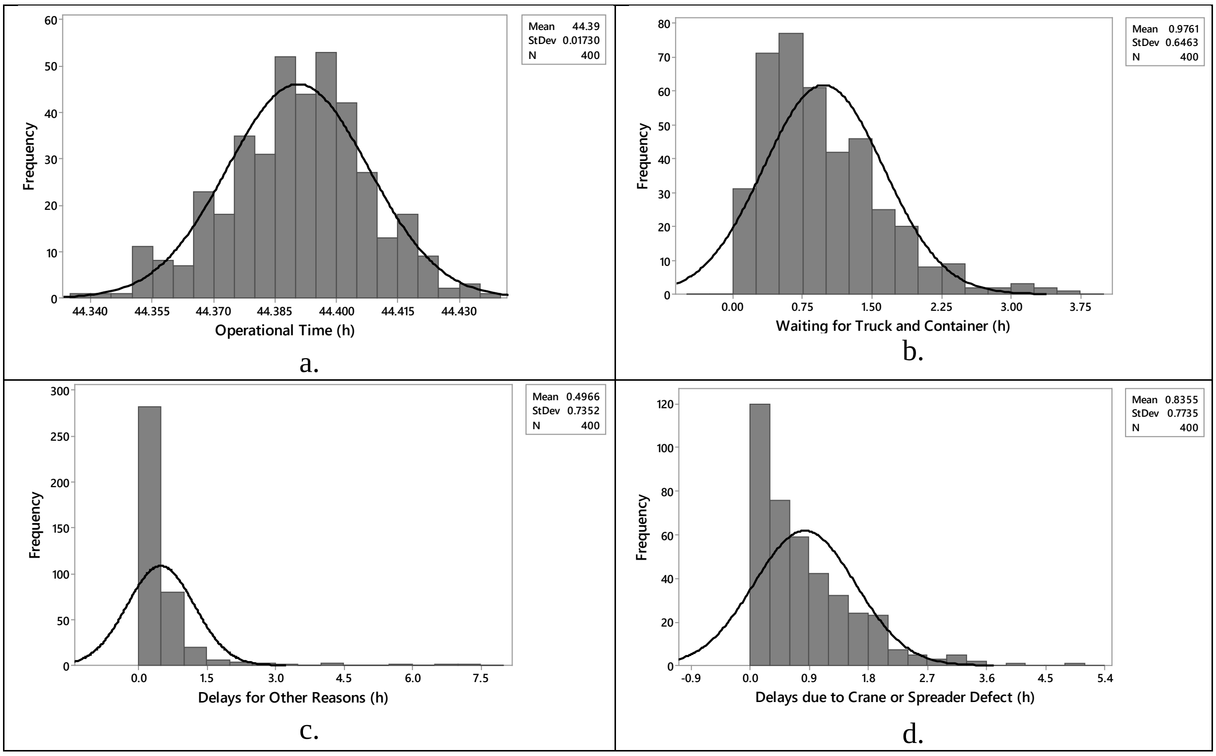


Figure 37. Low Tide (-0.5m) Case results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

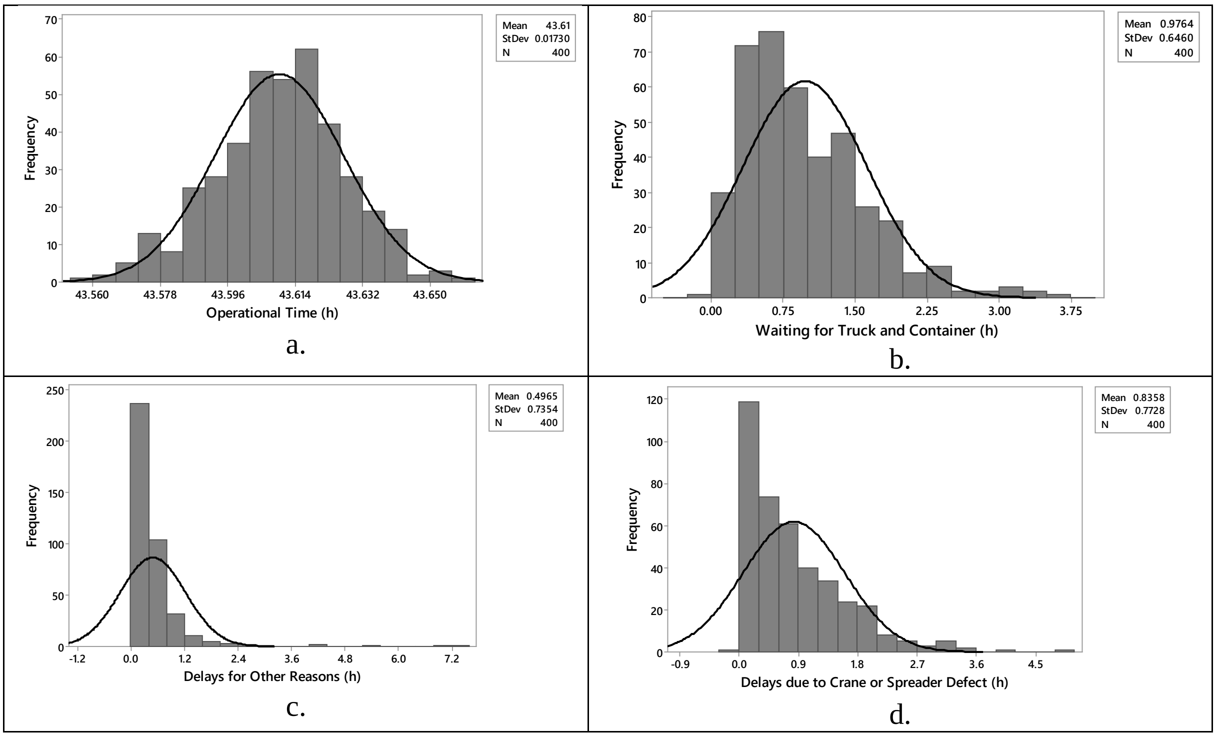


Figure 38. High Tide (+0.5m) Case results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

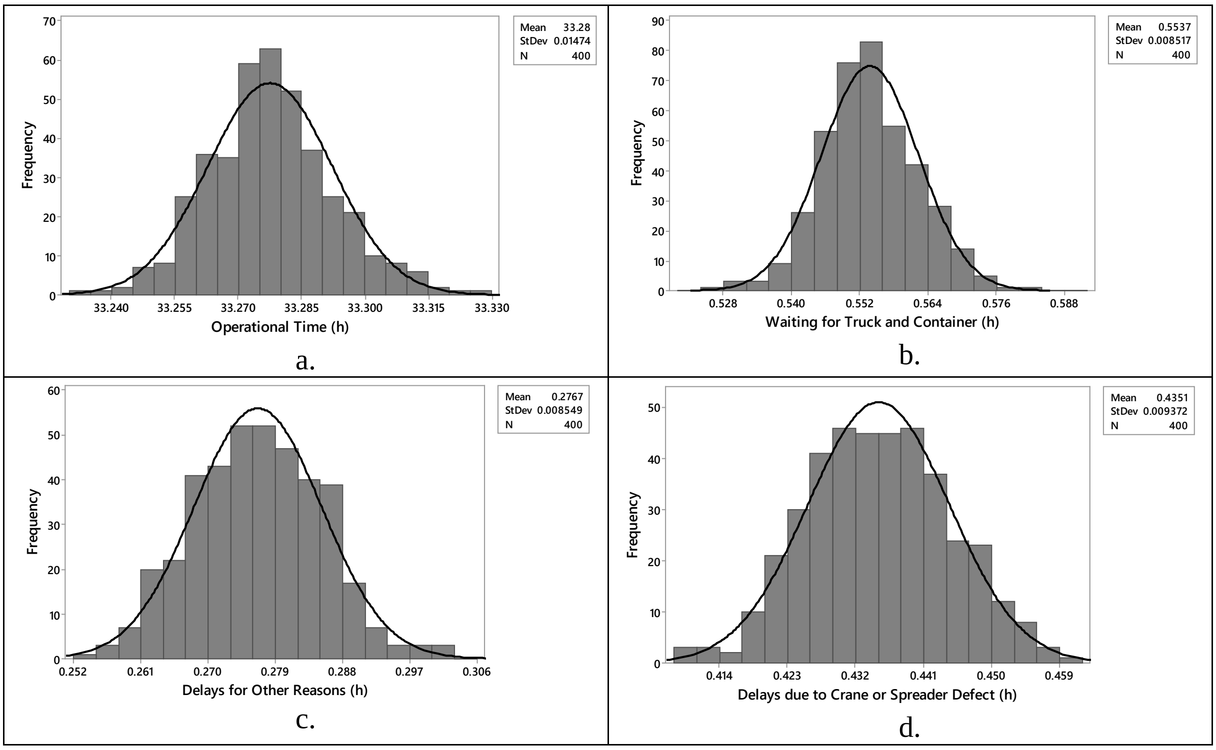


Figure 39. FEU Implementation (53%) Case results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

Appendix VII – Case 2 Results Multiple Number of Crane Usage on Port Efficiency

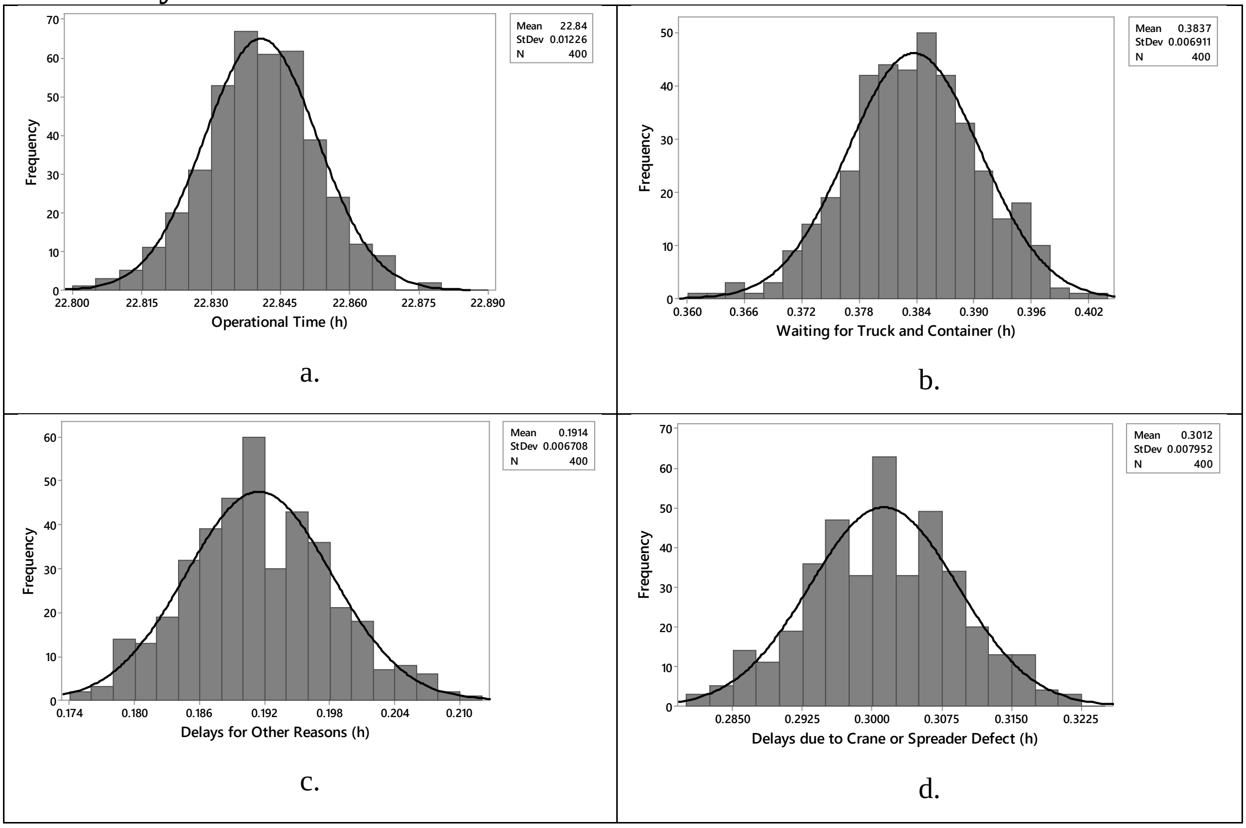


Figure 40. 2 Crane results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

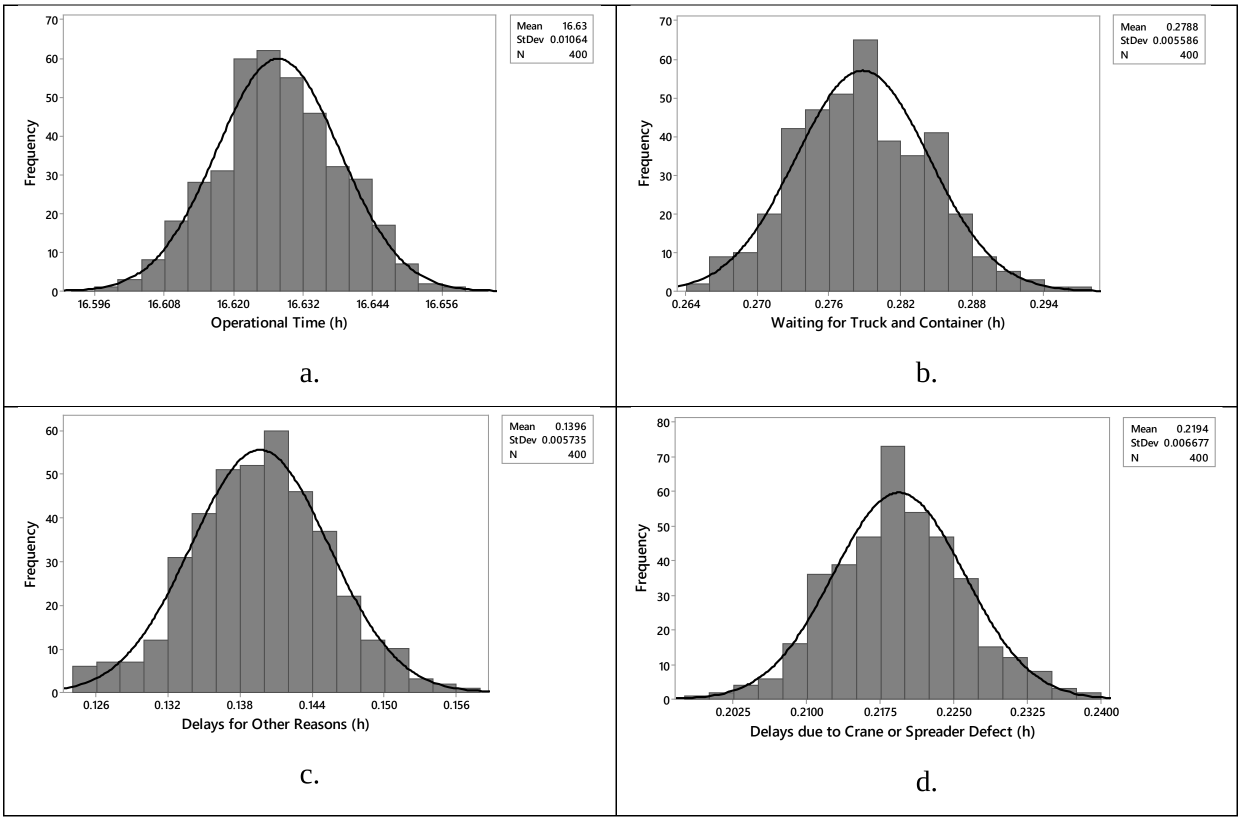


Figure 41. 3Crane results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

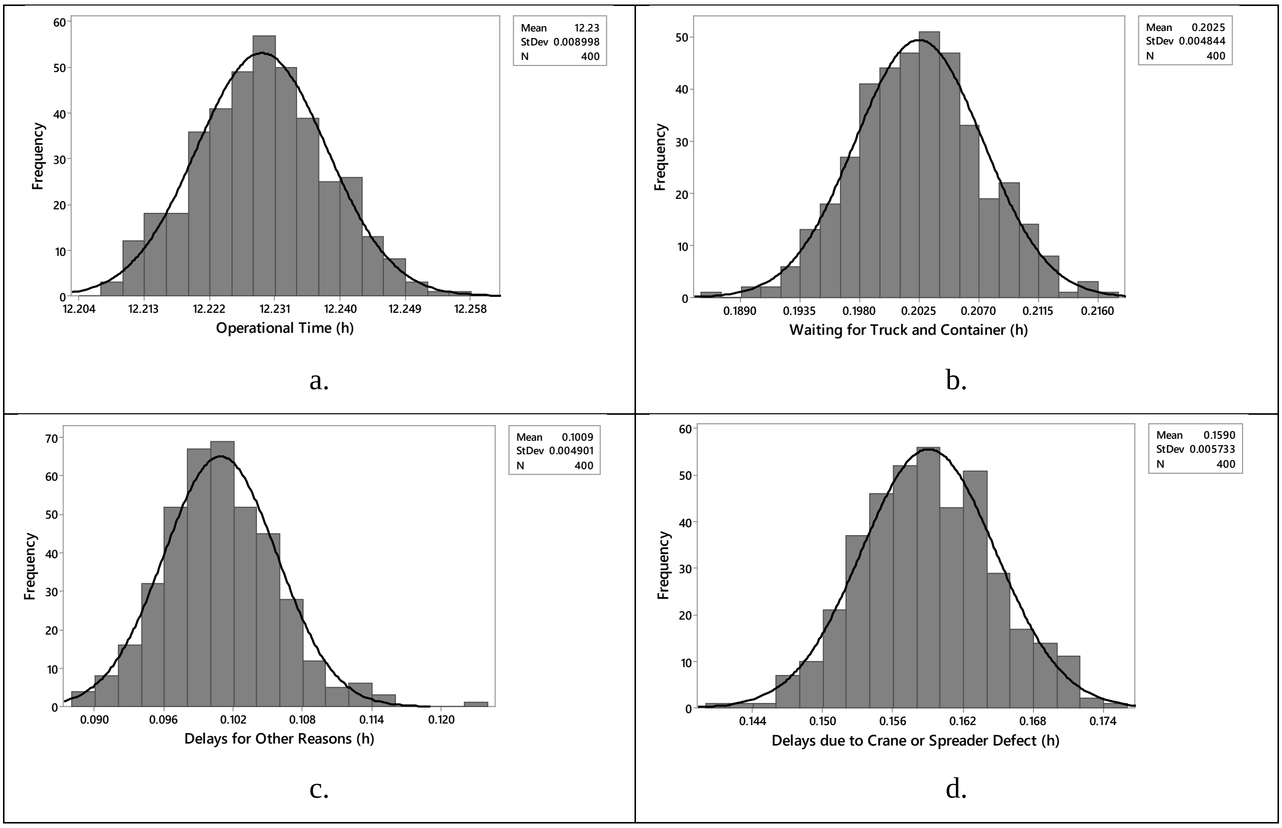


Figure 42. 4 Crane results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

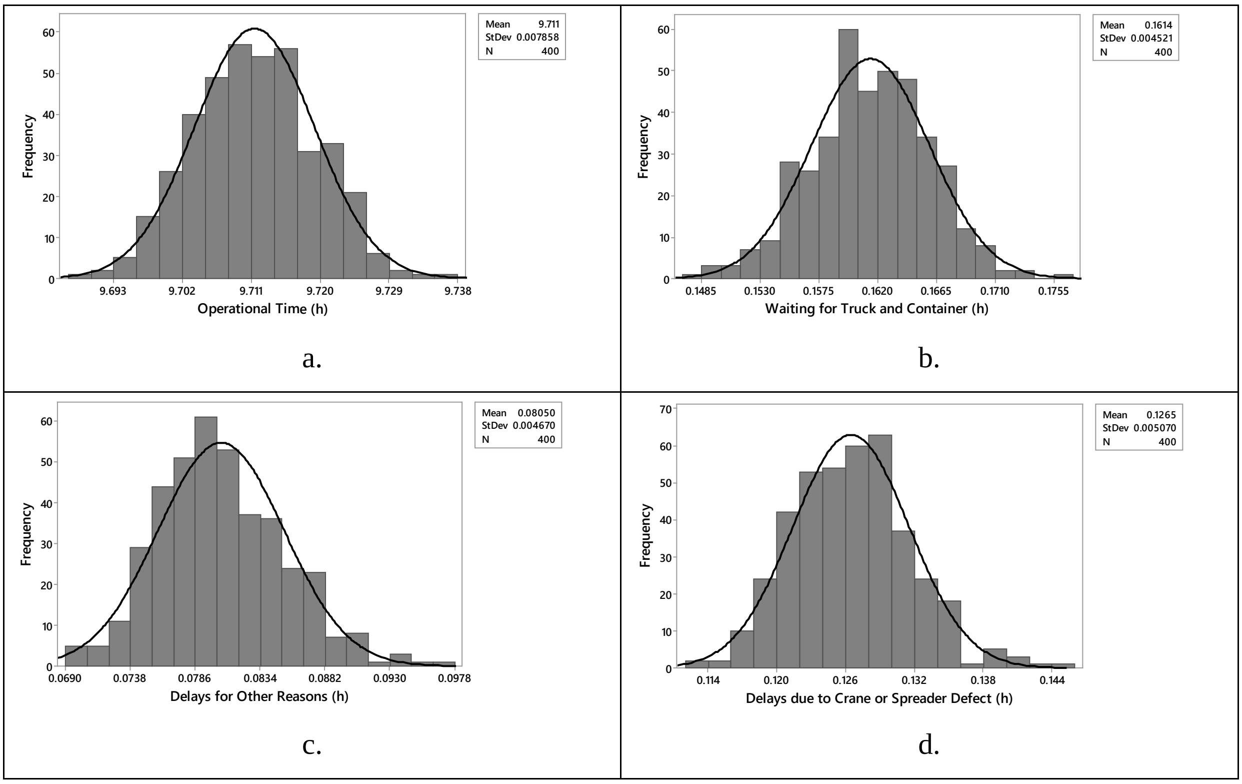


Figure 43. 5 Crane results, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

Appendix IIX – Case 3 - Examining Multiple Number of Crane Usage on Port Efficiency of FEU Implemented Stowage Plan Results

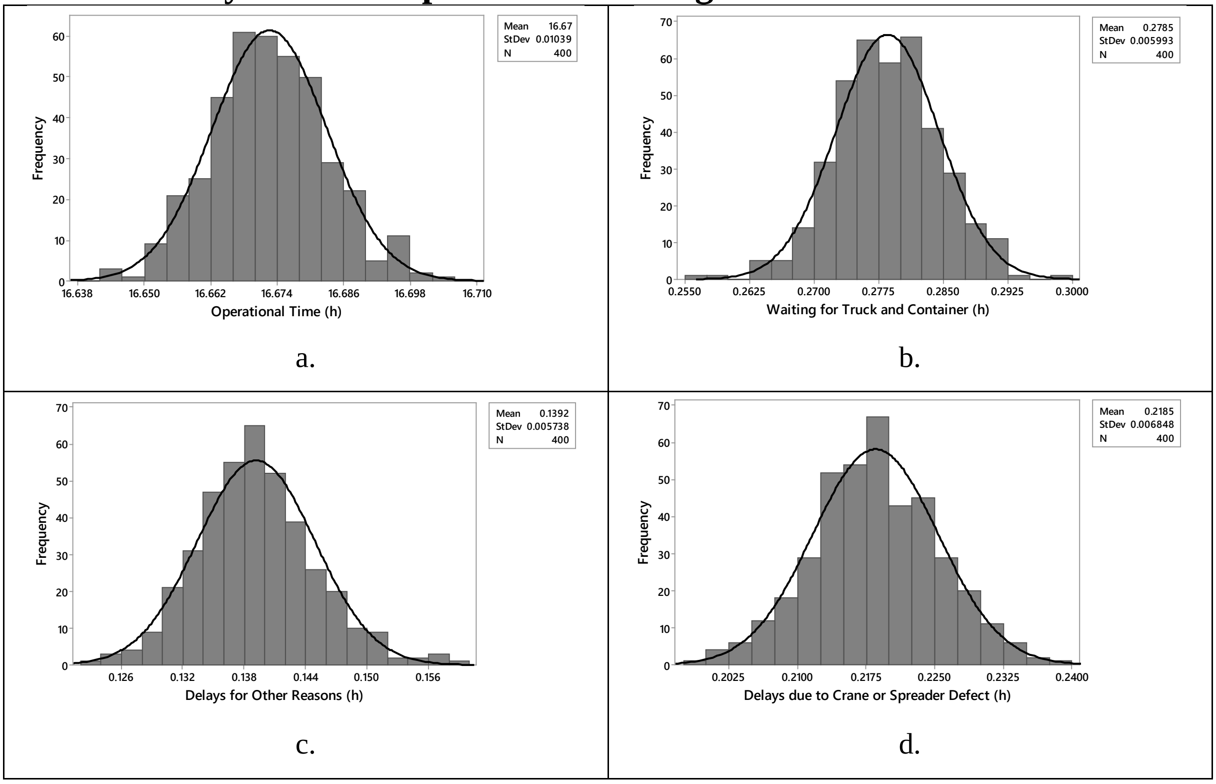


Figure 44. 2 Crane results for FEU implemented stowage plan,, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

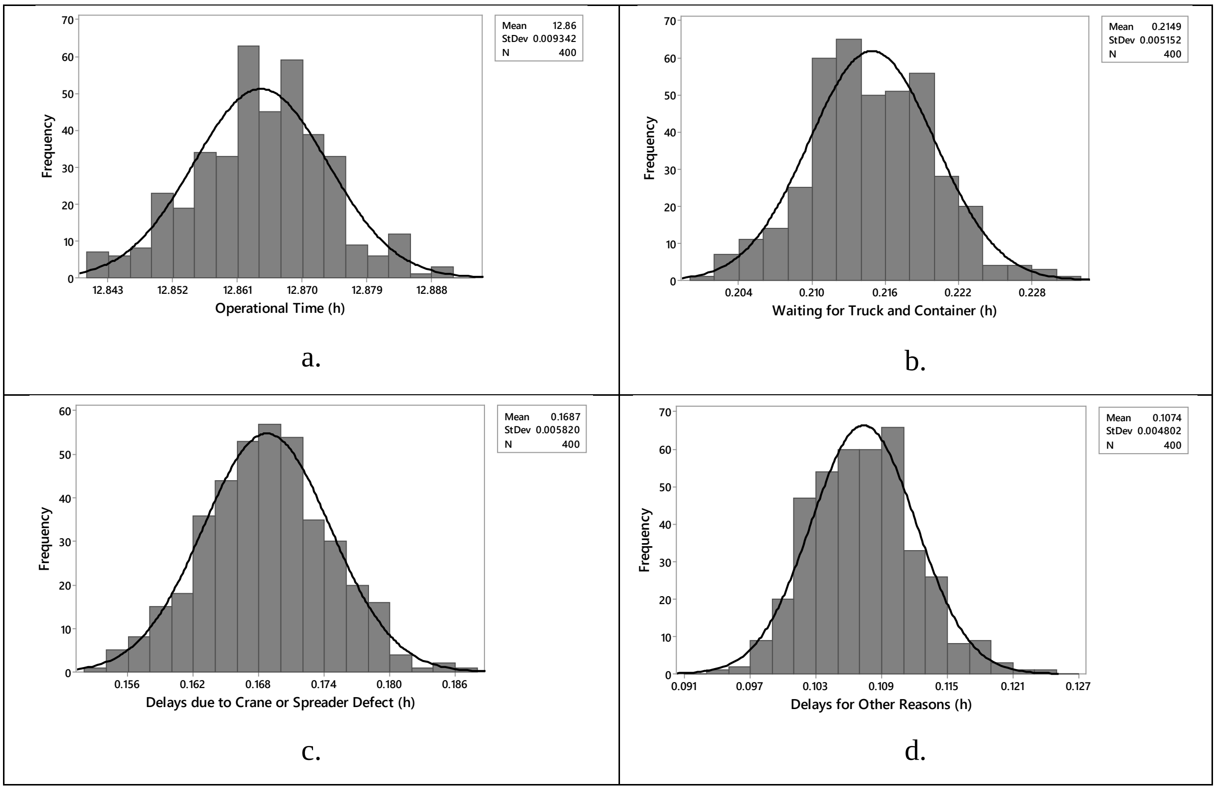


Figure 45. 3 Crane results for FEU implemented stowage plan,, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

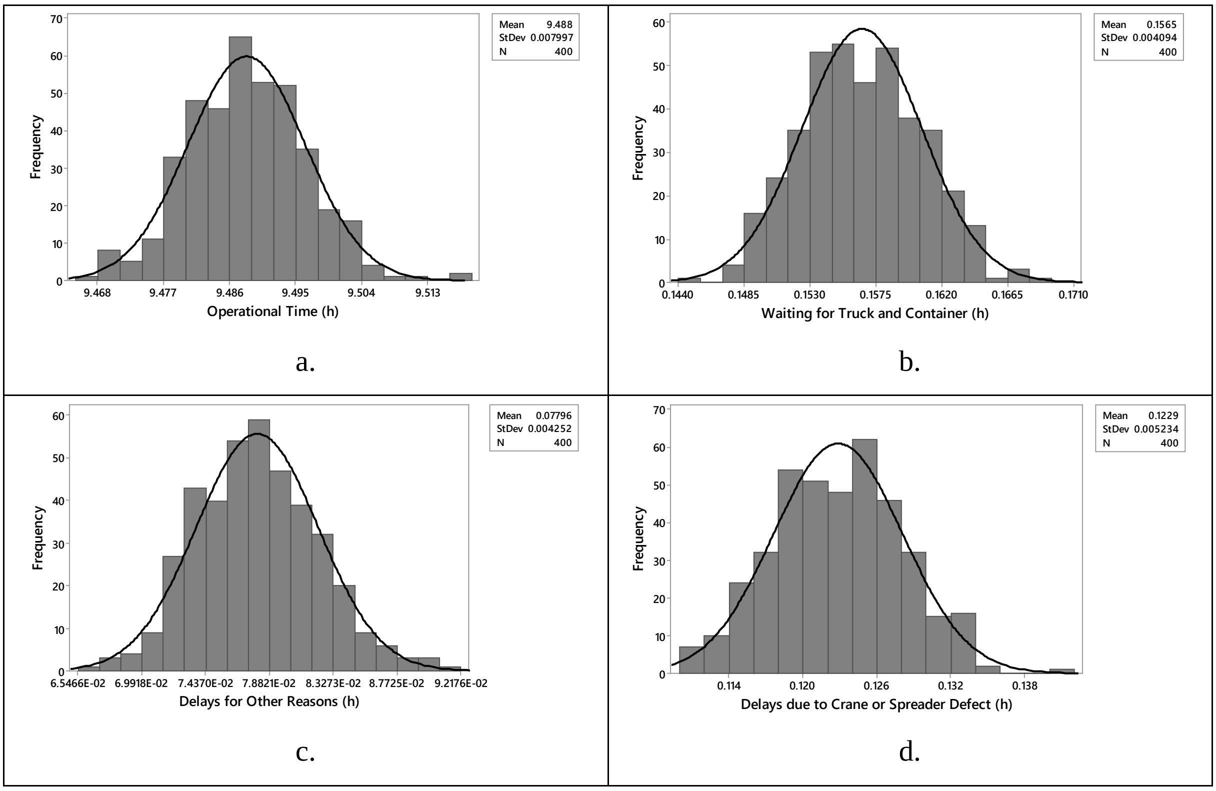


Figure 46. 4 Crane results for FEU implemented stowage plan,, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.

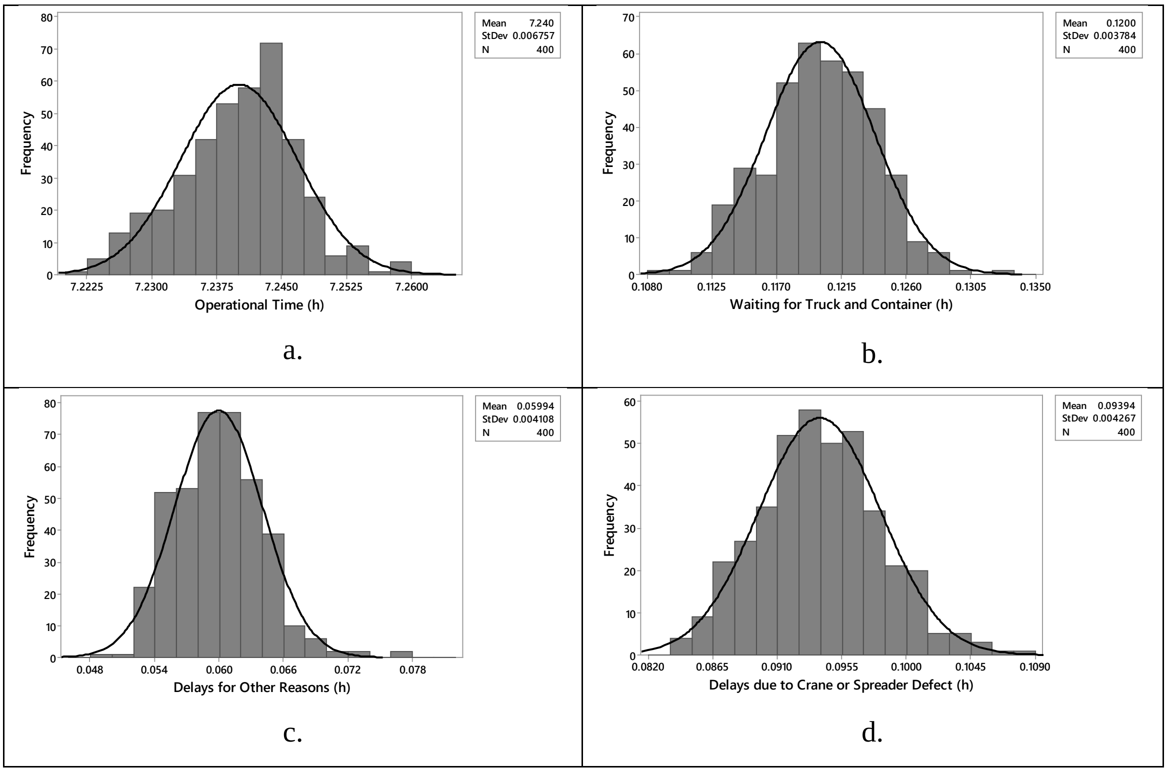


Figure 47. 5 Crane results for FEU implemented stowage plan,, where Gross Operational Time (a), Waiting for Truck and Container (b), Delays due to Other Reasons (c) and Delays due to Crane or Spreader Defect (d) results distributions are presented.